Reading and Writing
https://doi.org/10.1007/s11145-025-10688-y

Dyslexia in higher education: specific and global components of the reading profile

Francesca Vizzi[1,2] · Chiara Valeria Marinelli[3] · Marika Iaia[2] · Marco Turi[1] · Maria Diletta Carlino[1] · Pierluigi Zoccolotti[4,5] · Paola Angelelli[2]

Received: 6 February 2025 / Accepted: 19 July 2025

Abstract

More and more children with dyslexia progress in their school curriculum to college, raising interest in examining the characteristics of reading disorders in adulthood. In the present study, we investigated the reading abilities of Italian college students with dyslexia, examining vocal reaction times (RTs) in reading single words. We presented the entire set of words from the Varless database, considering several psycholinguistic variables, such as length, contextual rules, N-size, word frequency, and stress. Given the baseline differences between controls and adults with dyslexia, we carried out analyses of both raw RTs and z-transformed data to control for the presence of the over-additivity effect. We examined 23 adults with dyslexia and 30 controls. Results indicated a general slowing compared to control readers. This slowing was well described by a single global factor, in keeping with the difference engine model's (DEM) predictions. Students with dyslexia were more sensitive to the influence of length and frequency; however, these interactions vanished in the z-transformed analyses, indicating that they were due to over-additivity. A similar pattern was present in the case of stress assignment, one form of orthographic inconsistency in Italian. There were subtle differences between the two groups of subjects for a few psycholinguistic parameters. Despite prolonged school attendance, college students with dyslexia still show marked RTs slowing across various word stimuli. A global factor accounted for most (although not all) of the results when using analyses capable of controlling for over-additivity.

Keywords Dyslexia · Reading · Adults · Psycholinguistic factors · Reaction time

Francesca Vizzi and Chiara Valeria Marinelli have contributed equally to this work and share first authorship.

Extended author information available on the last page of the article

Published online: 09 October 2025

Introduction

Developmental dyslexia is a lifelong disorder that persists into adulthood. Individuals diagnosed with dyslexia in childhood typically continue to experience reading difficulties throughout their lives (e.g., Hatcher et al., 2002; Conti-Ramsden et al., 2009). In a very long follow-up study, literacy deficits were still present 44 years after the diagnosis (Maughan et al., 2009).

The phenomenon is of interest for several reasons. Firstly, individuals with dyslexia are at risk of school underachievement or dropping out (e.g., McLaughlin et al., 2014; Olofsson et al., 2015; Eloranta et al., 2019; Tops et al., 2020). Moreover, educational failure can lead to unemployment (e.g., Caspi et al., 1998; Eloranta et al., 2019), lower job satisfaction (such as lower wages and fewer promotions; Witte et al., 1998), and subsequent psychological, economic, and social problems (Gerber, 2012; Watson & Boman, 2005; Iaia et al., 2024).

In the last years, more and more individuals with dyslexia attend university (for example, in Italy, students with learning disabilities constitute 2.2% of the college population; Borgonovi et al., 2022). The few studies focusing on adults with dyslexia found lower performance, compared to control readers, in word and pseudoword reading (particularly in terms of reading speed), as well as in writing, naming speed, phonological processing, verbal memory, and vocabulary (for a study on Spanish see Suárez-Coalla & Cuetos, 2015; for a review see Reis et al., 2020). Despite ongoing reading difficulties (Eloranta et al., 2019), young adults with dyslexia may develop multiple compensation strategies based on the development of the orthographic lexicon or the capacity to use the semantic context to partially compensate for their decoding difficulty (Miller-Shaul, 2005; see also Corkett & Parilla, 2008). Additionally, particularly in languages with consistent orthographies, years of reading practice may enhance the efficiency of sublexical reading, potentially compensating to some extent for the reading deficit (Kemp et al., 2009; Afonso et al., 2015).

The development of compensatory mechanisms over time may significantly alter the reading impairment of adults with dyslexia compared to children with dyslexia. However, there is still a lack of research on the reading characteristics of adults with dyslexia, which limits our understanding of the long-term implications of reading difficulties in adulthood. Furthermore, research has focussed more on irregular orthographies such as English or Hebrew (Breznitz, 2002; Bruck, 1990; Lefly & Pennington, 1991; Shaywitz et al., 1999). By contrast, there is limited research on the reading profiles of adults with dyslexia in transparent orthographies. Individuals with dyslexia who read and write in transparent orthographies exhibit less severe deficits in accuracy of word recognition than those who have learned to read in more opaque orthographies but similar and severe deficits in terms of reading speed (Reis et al., 2020). This pattern indicates that reading slowness represents a critical issue for adults with dyslexia across all orthographies. In a similar vein, in a meta-analysis of studies on reading tasks and cognitive domains, Carioti et al. (2021) reported an interaction between age and orthography affecting word reading accuracy, and a significant main effect of age on pseudoword reading accuracy, but no effect of age or orthographic depth on reading speed. These results corroborate previous cross-

linguistic studies indicating slow reading as a marker of dyslexia in more transparent orthographies (e.g., Goulandris, 2003; Nergard-Nilssen & Hulme, 2014).

Reading speed continues to improve well beyond the age at which reading accuracy reaches a plateau, which occurs relatively early in Italian (the language object of the present study) after approximately three years of reading experience (Zoccolotti et al., 2009). This improvement continues into adulthood, indicating that reading represents a unique case of over-learning, where speed enhancements can still be observed after 15 years of reading experience (Carver, 1992; Brysbaert, 2019). This makes reading speed a reliable indicator for distinguishing between dyslexic and control readers, regardless of age and type of orthography (Reis et al., 2020; Carioti et al., 2021).

An effective paradigm to investigate the speed deficit in dyslexia in regular orthographies is measuring vocal reaction times (RTs) in word naming (i.e., time taken to initiate reading the stimulus). There is a consolidated tradition on the general characteristics of this measure (e.g., Wagenmakers & Brown, 2007) and on its efficacy to evidence the factors underlying visual word recognition (for a review see Yap & Balota, 2015). In particular, this paradigm allows for examining the impact of various psycholinguistic variables on sublexical reading (such as word length and orthographic complexity) and lexical reading (including word frequency and neighbourhood density, N-size) both in opaque orthographies, such as English (Yap et al., 2012) or French (Bonin et al., 2018) and transparent orthographies, such as Spanish or Italian, (Barca et al., 2002).

Studies on Italian students with dyslexia suggest the following: (1) individuals with dyslexia demonstrate a more marked effect of word length, with longer words resulting in longer RTs, i.e., index of significant reliance on sequential decoding, a characteristic observed not only in children during the early stages of reading development (Zoccolotti et al., 2005) but also in sixth- and seventh-grade children with dyslexia (De Luca et al., 2008; Judica et al., 2002; Spinelli et al., 2005; Zoccolotti et al., 1999); (2) children with dyslexia generally show overall slower RTs across all reading conditions tested, including words varying for frequency and length or nonwords varying for frequency and pronounceability (e.g., Zoccolotti et al., 2008; Marinelli et al., 2014). This slowness points to a non-task-specific, or "global", factor contributing to the observed group differences.

Various models aim to account for the role of global components in group differences related to overall processing speed (such as young and old adults). Here, we refer to two such models: the different engine model (DEM) by Myerson et al. (2003) and the rate-and-amount model (RAM) by Faust et al. (1999), as they provide interesting complementary predictions to be tested. According to the DEM (Myerson et al., 2003), there is a nearly linear relationship between condition means and the corresponding standard deviations (SDs), such that slower conditions are associated with larger interindividual variability. Note that this relationship indicates a systematic deviation from the homogeneity of variance assumption, which underlies the use of parametric statistics (such as ANOVAs). The relationship between means and SDs represents a key rule or law (see also Wagenmakers & Brown, 2007). Critically, the model predicts that this relationship is invariant across groups with different overall processing speeds (young and old adults in the original analyses by Myerson et al.,

2003). A further prediction is that the condition means of a given (slow) group (e.g., older individuals) will be linearly related to those of a (faster) group (e.g., young adults), indicating a global factor accounting for the slowness difference (expressed quantitatively by the slope of the linear regression). These tests allow for the detection of global components in generating differences between target groups.

While a global factor may account for differences across several experimental conditions, this does not necessarily imply that all conditions contribute to such a factor. Thus, in several studies, we observed that children with dyslexia are homogeneously delayed across all word and nonword reading conditions (e.g., Zoccolotti et al., 2008; Martelli et al., 2014); however, in the presence of pictorial stimuli (Zoccolotti et al., 2008; De Luca et al., 2017) or single letters/bigrams (De Luca et al., 2010), group differences vanished or were very small. So, according to the DEM, the "domain" to which the global factor applies needs to be empirically determined (Myerson et al., 2003).

When two groups vary by some general speed factor, one expects larger group differences under more difficult conditions (and smaller group differences under easier conditions) over and above the specific effect of a given experimental manipulation (over-additivity effect). Therefore, over-additivity can modulate interactions between groups and conditions when two groups differ in general ability (Faust et al., 1999), as in the case of children with dyslexia and control readers. According to the RAM (Faust et al., 1999), this effect can be controlled using various data transformations, including the intra-individual z-score transformation. When we examined the greater length effect shown by children with dyslexia following the procedure outlined by Faust et al. (1999), we observed that children with dyslexia still showed a greater length effect than control children, although the group difference was considerably smaller once over-additivity was considered (Zoccolotti et al., 2008; De Luca et al., 2010). In RAM's perspective, word length emerged as a specific factor accounting for the group difference over and above the general slowness exhibited by children with dyslexia.

In addition to word length, studies using vocal RTs examined various lexical effects in Italian children with dyslexia. They reported greater frequency effects in children with dyslexia than in controls (Barca et al., 2006; Marinelli et al., 2013). However, when examined using z-transformed scores, children with dyslexia showed a frequency effect like that of control children (Paizi et al., 2013), indicating the influence of over-additivity on this pattern of findings. Consistent findings were observed for lexicality: children with dyslexia showed larger lexicality effects in raw data but not when over-additivity was controlled for (Paizi et al., 2013). Moreover, other lexical effects in reading were present in Italian children with dyslexia. For instance, they showed greater facilitation than controls in reading low-frequency words with a large N-size (Marinelli et al., 2013), indicating they benefitted from lexical activation spreading from dense neighbourhoods. Notably, this effect was evident in the z-transformed data analysis, indicating independence from the over-additivity effect.

Studies examining stress assignment are also in line with research showing that children with dyslexia are sensitive to the lexical quality of the stimulus. In Italian, most three- and four-syllable words have stress on the penultimate syllable, considered the dominant (or regular) stress pattern. However, a smaller proportion

of polysyllabic words have stress on the antepenultimate syllable, considered the non-dominant or irregular stress pattern. This disproportionate distribution of stress assignment in Italian can be seen as a source of irregularity, as in deeper orthographies like English (Colombo, 1992). So, stress assignment is lexically determined (i.e., not marked or rule-based), although readers also rely on distributional properties such as word endings (stress neighbourhood) to aid lexical processing (Burani & Arduino, 2004). In line with studies on lexical effects, children with dyslexia did not exhibit more regularisation errors than control children, with stress assignment largely influenced by the composition of the stress neighbourhood: words with many stress friends were read more accurately than words with many stress enemies, irrespective of the dominant or non-dominant stress pattern (Paizi et al., 2011b). This finding indicates that children with dyslexia are sensitive to the distributional properties of the language (Paizi et al., 2011a). Note that accuracy is a sensitive measure of performance among children due to the substantial proportion of stress errors with polysyllabic words even in an orthographically regular orthography. However, one may expect RTs to be sensitive in detecting the effect of stress dominance (as will be done in the present study), even though, to date, this test has not yet been done (as in children, the population tested so far, manipulations involving stress assignments are typically associated with relatively high proportions of errors; Paizi et al., 2011b).

Interesting data on lexical reading effects in children with dyslexia have come from a different paradigm, such as the orthographic judgment task (Marinelli et al., 2009, 2020; Angelelli et al., 2010). This task (in addition to the study of vocal reaction times) is particularly well-suited to assess lexical reading processes in languages like Italian, which has relatively few written-to-oral inconsistencies. Children with dyslexia showed difficulties in detecting pseudo-homophones, suggesting a greater reliance on sublexical processing. However, like typically developing children, they also displayed a frequency effect, with high-frequency words being judged more accurately than low-frequency ones. The difficulty with low-frequency words was interpreted as a deficit in lexical expansion, reflecting a smaller set of orthographic representations in the lexicon compared to children without dyslexia.

Overall, data on lexical properties derive from different experimental paradigms and reveal a complex pattern of findings. Children with dyslexia are sensitive to lexical parameters, including frequency, lexicality, and N-size. Indeed, they even show an advantage from lexical activation spreading from dense neighbourhoods where control children do not presumably need it (Marinelli et al., 2013). However, there is also evidence that the orthographic lexicon may be less developed (fewer orthographic representations in the lexicon than in typically developing children) and that they may be less able to use lexical information efficiently based on context demands. In a study examining the influence of list context on word frequency and length effects, Paizi et al. (2011a) observed that controls showed a list context effect for high- and low-frequency words. In contrast, children with dyslexia showed a list context effect only for high-frequency words, indicating inefficiency in activating entries in the orthographic lexicon as a function of context demands. Finally, evidence on stress assignment suggests that children with dyslexia may be sensitive to the statistical properties of the language, which may help them partially compensate for their lexical deficiencies (at least in some conditions).

In the present study, we investigated the reading abilities of Italian adults with dyslexia using the vocal RT paradigm to understand the factors influencing the magnitude and severity of their reading impairments in a consistent orthography. Two key issues arise when assessing the performance of young adults. First, reading speed continues to improve over an extended period (beyond 15 years of practice). Therefore, it is important to examine whether reading slowness persists in adults with dyslexia. Relatedly, we wished to examine whether the expected reading slowness of adults with dyslexia would be comparable to that of younger children with dyslexia (see method for details on this comparison). Second, as overall performance can influence the magnitude of psycholinguistic effects, it is crucial to determine whether sublexical and lexical psycholinguistic variables exert a specific or merely spurious effect (due to over-additivity) in adults with dyslexia.

We considered several psycholinguistic variables: length, contextual rules, N-size, word frequency and stress. We examined the possible role of a global factor in accounting for the group differences by testing the critical predictions of the DEM (Myerson et al., 2003). Given the baseline differences expected between controls and adults with dyslexia, we carried out analyses of both raw RTs and z-transformed data. Following the RAM (Faust et al., 1999), the interactions with the group factor significant in both the analysis of raw scores and z-transformed scores indicate the specific influence of a particular variable. In contrast, interactions significant only in the analyses of raw data but not in those with z-transformed values, indicate spurious effects due to over-additivity. Overall, this approach helps to distinguish genuine from spurious effects, providing a clearer understanding of underlying reading deficits.

Method

Participants

The participants were 23 Italian college students with dyslexia (9 M, 14 F) with a mean age of 23.39 years (SD = 2.85). The recruitment was carried out through a screening project in which participants voluntarily completed a standardized risk questionnaire (Vinegrad Plus; LCS SUA Montesano et al., 2020). All individuals who scored above the threshold on the risk assessment were invited to participate to the study.

The selection criteria for inclusion in the dyslexic group were: (i) a reading delay on a standardised passage reading or word and nonword reading test (at least 1.65 SDs below the mean of the normative sample for reading speed or accuracy in the LSC-SUA reading tests; Montesano et al., 2020; see the following paragraphs); (ii) and an IQ in the normal range (i.e., Full-Scale Intelligence Quotient (FSIQ) ≥ 85, as measured by the Wechsler Intelligence Scale for Adults-IV (2008); normative Italian data by Orsini & Pezzuti, 2013).

The reading comprehension was also evaluated, by administering the written comprehension test from the same battery, in order to have an index of functional reading. All subjects performed within the norms compared to the normative reference values.

All study participants were evaluated at the time of the experiment for their cognitive, reading, and spelling abilities upon enrolment by our psycho-diagnostic service at the University of Salento, ensuring that the profiles described in the study are up to date. Comprehensive anamnestic data, including educational background, family history of learning disorders, and perceived challenges in daily literacy activities, were also collected to integrate the psychometric data.

Notably, thirteen participants had received a diagnosis of dyslexia before entering college, some as early as primary school and others during middle or high school; for the other eleven, the diagnosis was made at the time of college admission. All subjects were assessed at the time of enrolment in the study, independently of whether they had a previous dyslexia diagnosis or not.

Thirty college students (15 M, 15 F), 20–30 years of age (mean age = 22.8, SD = 2.43), participated in the experiment as control subjects. All control subjects performed within the norm for both reading speed and accuracy in both reading tests and had an intelligence level in the normal range.

Table 1 reports the demographic characteristics, cognitive scores, and performance on reading tasks for both dyslexia and control groups, including means and standard deviations for raw and standardized (z) scores based on standard reference data. The two groups did not differ significantly in age. However, they differed in Full-Scale Intelligence Quotient (FSIQ; $t = 3.39$; $p = 0.001$), with the control group showing higher scores, whereas no significant group difference emerged in the General Ability Index (GAI; $t = 1.35$; n.s.). Given that the FSIQ is often influenced by working memory and processing speed -domains commonly impaired in individuals with dyslexia and other neurodevelopmental conditions- the GAI may represent a more reliable estimate of overall cognitive ability in this population (Scorza et al., 2023; Theiling & Petermann, 2016).

As expected, participants with dyslexia demonstrated significantly lower performance compared to controls in reading fluency and accuracy across all tasks except for reading comprehension, where no significant differences emerged between groups. In the passage reading task, control participants read significantly faster than those with dyslexia ($t = 12.01$, $p < 0.001$). Moreover, dyslexic participants made considerably more errors than controls in the same task ($t = -8.60$, $p < 0.001$). These group differences were even more pronounced in the single-word and nonword reading tasks. In the single-word reading task, individuals with dyslexia were significantly slower ($t = 4.98$, $p < 0.001$) and less accurate ($t = -4.60$, $p < 0.001$) than their typically developing peers. A similar pattern emerged in the nonword reading task, where dyslexic participants exhibited reduced speed ($t = 2.00$, $p < 0.05$) and higher error rates ($t = 3.83$, $p < 0.001$) compared to controls.

Materials

Reading assessment

The reading level was assessed by a standard reading achievement battery (LSC-SUA, Montesano et al., 2020). The battery comprises a meaningful passage reading

Table 1 Demographic characteristics and descriptive statistics (means and standard deviations) of Raw and standardized scores on reading and general cognitive tests in dyslexic and control participants

	Dyslexia group		Control Group			
	M (SD)		M (SD)		t (51)	*p*
Age	23.39 (2.85)		23.9 (2.45)		0.79	n.s
FISQ (WAIS-IV)	100.86 (12.61)		111 (11.69)		3.39	0.001
GAI (WAIS-IV	106.04 (12.87)		110 (11.06)		1.35	n.s.
Reading tests	**Raw scores**	**z scores**	**Raw scores**	**z scores**		
Passage (syllable/sec).	4.44 (0.61)	-1.47 (0.60)	5.99 (0.54)	0.04 (0.53)	12.01	<0.001
Passage errors	7.54 (4.12)	3.48 (2.48)	2.17 (1.05)	0.24 (0.63)	-8.60	<0.001
Single words (syllable/ sec).	3.21 (0.80)	-1.53 (0.79)	4.40 (0.81)	-0.51 (1.12)	4.98	<0.001
Single words (errors)	3.26 (3.04)	0.45 (1.35)	1.11 (1.34)	-0.50 (0.60)	-4.60	<0.001
Single nonwords (syllable/sec).	1.89 (0.39)	-1.41 (0.52)	2.92 (0.49)	-0.06 (0.64)	2.00	<0.05
Single nonwords (errors)	5.21 (4.27)	0.78 (1.61)	2.37 (2.02)	-0.29 (0.76)	-3.83	<0.001
Passage comprehension	10.09 (2.25)	-0.04 (0.89)	10.19 (2.09)	-0.00 (0.83)	0.85	n.s.

test, a single-word and non-word reading test and a reading comprehension test. Following is a synthetic description of the reading battery.

Reading assessment: passage reading

The test consists of a text passage ("Floripa") based on content with which all participants may have relatively low and similar familiarity. This would include words of different frequency and linguistic complexity, sentences of similar length and structure to those typically encountered by an adult, and rare, and presumably unfamiliar, terms that necessarily require the use of sublexical processes (such as Floripa, Florianopolis, Cananvierias and Lagoa, all names of places). The passage is 593 syllables long. Participants were asked to read the text aloud. The dependent measures were reading speed (time in sec/number of syllables read) and accuracy (number of errors adjusted for text read) were measured. The normative data refer to 667 students (Montesano et al., 2020).

Reading assessment: word and nonword reading

The test consists of lists of words and non-words to read aloud as accurately and quickly as possible. There are four-word lists, each of 28 stimuli: (1) short high-frequency words, (2) short low-frequency words, (3) long high-frequency words, and (4) long low-frequency words. There are two non-word lists, also consisting of 28 stimuli each. The non-words are derived by syllabic permutation of a subset of words constituting the word lists. They are divided into (1) short non-words, made up of 2/3 syllables; (2) long non-words, made up of 4 syllables. Speed and accuracy parameters are considered for both words and non-words. Speed is assessed in syllables per second (for words: the sum in seconds of partial times obtained from the four lists divided by the 352 syllables that make up the word test; for nonwords: the sum in seconds of partial times obtained from the two lists divided by the 176 syllables that make up the nonword test). For the accuracy parameter, one error is awarded for each omitted or incorrectly read word or nonword. The normative data refer to 667 students for words and 666 for non-words (Montesano et al., 2020).

Reading assessment: comprehension

The text comprehension was assessed with the Passage A ("*The Atlantis of the Adriatic*"). The student silently reads the text without a time limit, followed by 14 multiple-choice questions with four alternatives. The questions vary in type, including both general-inferential and specific questions. The accuracy parameter is considered: one point of error is awarded for each correctly answered question. The normative data refer to 552 students (Montesano et al., 2020).

Experimental reading task

Computerised reading-aloud tests were performed on words reported in the Varless 2 database (Burani et al., 2015; http://www.istc.cnr.it/it/grouppage/varless2), a

database of 626 morphologically simple, 4–9 letters long Italian singular nouns, not ambiguous for grammatical category or meaning. Several psycholinguistic factors are considered for these nouns, including the age of acquisition (AoA), familiarity, imaginability, concreteness, word frequency, number of neighbours (N-size), frequency of bigrams, length, stress, and visual confusability.

The computerised reading-aloud test envisaged individually presented words presented through the SuperLab software. After a fixation point lasting 750 ms, words were displayed in the centre of the computer screen. The stimulus remained on the screen until uttered by the subject. Each letter (in the Verdana 42 font) extended 0.4 cm horizontally (or 0.4 deg). The experimenter manually scored errors with the support of an audio recorder. Self-corrections were considered errors. Vocal RTs of incorrect responses were not analysed.

Data analysis on vocal RTs

Initially, false, missing, and incorrect responses were identified and excluded from the analysis. We considered RTs of less than 300 ms as missing data, accounting for approximately 1.06% of the total data points.

Test of global components

We first examined the presence of global components within the data, as postulated by the DEM (Myerson et al., 2003). Specifically, the model predicts that the standard deviations of various conditions will be nearly linearly related to the corresponding means of those conditions (see Eq. 7, p. 271; Myerson et al., 2003). Based on the DEM, we anticipated that this linear relationship would hold for two groups differing in global responding speeds. One important implication of this relationship is that it enables us to separate two components - referred to as compartments by Myerson et al. (2003) - of overall response times: a sensorimotor (or peripheral) and a cognitive (or central) compartment. The DEM predicts the sensorimotor compartment as a constant value (indicated by the intercept on the x-axis of the relationship between means and standard deviations) and invariant across groups with differing global responding speeds. The predictions made by the DEM relate to discrete manipulations conducted within an experiment. However, in our current study, the psycholinguistic parameters varied continuously across the stimuli. To test the hypothesis of the DEM, we divided the data distribution into approximate deciles, which allowed for more data points and improved the accuracy of our estimations.

Additionally, we examined by a Brinley plot the DEM's prediction that the condition means for the slower group (adults with dyslexia) would be linearly related to those of the faster group (controls) (Myerson et al., 2003). The slope of the linear regression in the plot reflects the degree of slowness in the slower group (Myerson et al., 2003).

Test of psycholinguistic variables

A linear mixed-effects model with intercepts and psycholinguistic variables was applied. We carried out two sets of analyses.

In the first set, conducted on the entire stimulus set of the Varless, we analysed the effects of group, length, contextual rules, N-size, and word frequency factors, along with their interactions, on vocal RTs. We treated these factors as fixed effects and items and participants as random effects to account for deviations in the slopes of the fixed effects.

In the second set, we aimed to evaluate the effect of stress (penultimate vs. antepenultimate syllable) on vocal RTs. Note that disyllabic words have their stress always on the penultimate syllable; thus, we carried out the analyses on a database from which disyllabic words were excluded (277 out of 626 words). This model assessed the influence of group and stress, considering the effect of word frequency and their interactions and items and participants as random factors. In all these analyses, in the case of continuous variables (e.g., length, frequency, N-size), the program provides the means of the tertiles.

For both types of analyses, we conducted separate mixed linear model analyses on vocal RT raw data (r) and RT z-transformed data (z). Raw data were transformed into z-scores by taking each individual's condition means, subtracting their overall mean and dividing it by the SD of their condition means (therefore, each individual has an average of 0 across conditions and an SD of 1). This transformation re-scales individual performances to a unique reference; hence, it allows controlling for global components while it preserves the information regarding individual variability across experimental conditions. According to Faust et al. (1999), this z-score transformation allows for examining the role of specific factors while controlling for global components, such as over-additivity. Presenting the results of these two types of analyses together will help highlight which main effects and group-by-condition interactions are genuine and which point to an over-additivity effect.

Computation of the absolute RTs difference between groups

Finally, we examined the absolute RTs difference between the two groups of subjects. According to the DEM (Myerson et al., 2003), the overall response time includes both the sensorimotor (or peripheral) compartment (expected to be invariant across groups) and the portion of the response connected to the cognitive (or central) compartment. Therefore, as group differences in raw RT values reflect the combination of a portion of the response sensitive to the group difference (cognitive compartment) and one expected to be constant (sensorimotor compartment), we expected group differences to be diluted compared to the outcome of procedures (such as the Brinley plot) which can isolate the cognitive component of the response.

In a previous re-analysis of several studies (see Zoccolotti et al., 2015) to compare dyslexic and control individuals, we calculated the ratio of the absolute RTs between the two groups. We found this measure to be more appropriate for assessing effect size given that the data violate the assumption of homogeneity of variance, as participants with dyslexia exhibit significantly greater variability than control participants.

These data are presented alongside those from the developmental data by Zoccolotti et al. (2015) to provide a preliminary index of the stability of the reading deficit.

Results

Test of global components

The plot between decile means and standard deviations is presented in Fig. 1. An inspection of the figure indicates some main findings:

- As expected by the DEM (Myerson et al., 2003), standard deviations tend to grow systematically with increasing decile means.
- Data for both controls and adults with dyslexia are well described by a single relationship, best captured by a second-order polynomial, which accounts for 99% of the variance (consistent with Eq. 7, from Myerson et al., 2003).
- A linear regression explains the data less well ($y = 0.37x - 158.4$; $R^2 = 0.95$). However, the linear regression parameters are useful to test additional predictions of the DEM (Myerson et al., 2003).
- In particular, the model states that the intercept of the linear regression on the x-axis (here, 428.1 ms) represents an estimate of the sensory-motor compartment

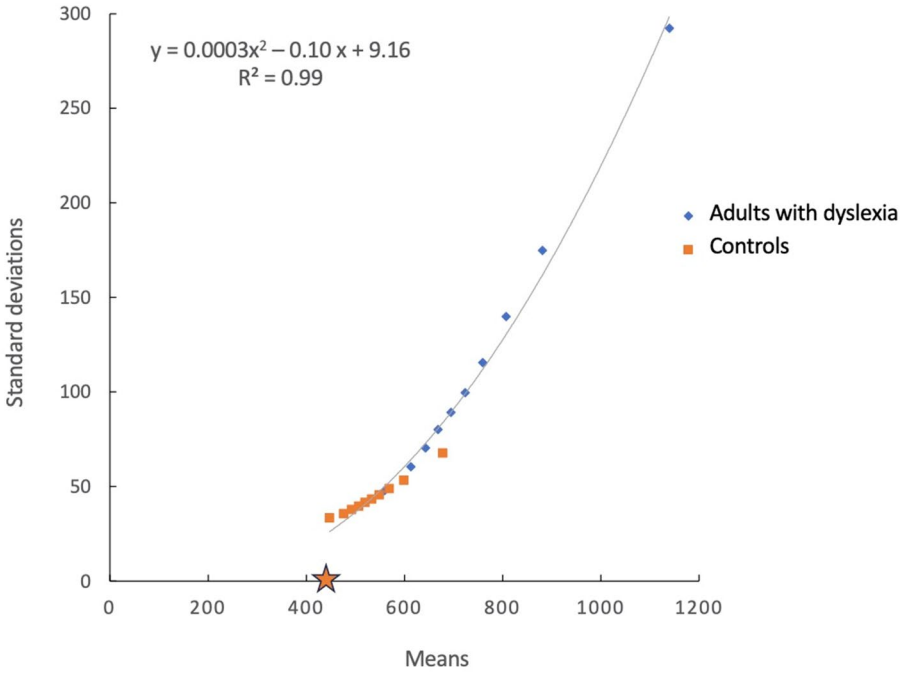

Fig. 1 Plot between the decile means and corresponding inter-individual standard deviations. The asterisk marks the intercept on the x-axis of the linear regression (not shown) between the two sets of data (which represents an estimate of the sensorimotor component of the response according to the DEM)

accounting for the peripheral component of the response.
– Further, the slope of the linear regression (i.e., 0.37) represents an estimate of the degree of co-variance between means and SDs; in particular, the DEM posits that it represents an estimate of the average inter-correlation among processing stages.

The Brinley plot between the data of controls and adults with dyslexia is presented in Fig. 2. An inspection of the figure indicates a few major findings:

– As expected, the data points are all above the diagonal line marking the iso-performance, i.e., the decile means of the adults with dyslexia are systematically slower than those of the control group, as indicated.
– The decile means of the group of adults with dyslexia increase linearly as a function of the decile means of the control group; this regression accounts for a large proportion of variance ($R^2 = 0.98$).

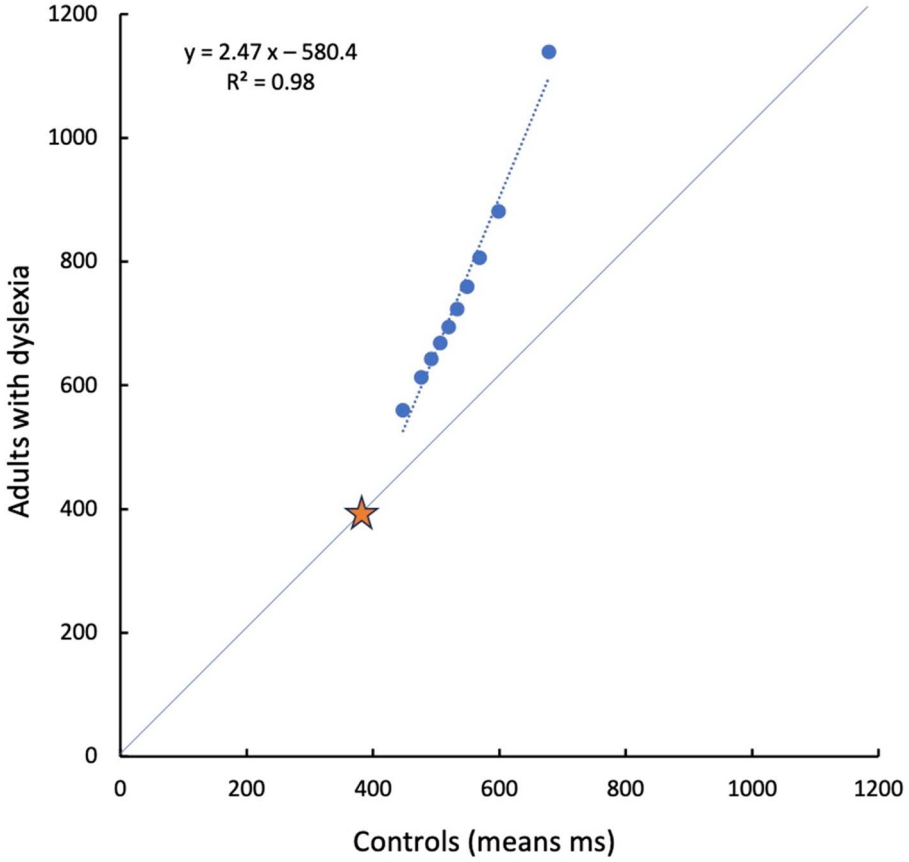

Fig. 2 Brinley plot between the decile means of the controls and those of the adults with dyslexia. The diagonal marks the iso-performance reference of the two groups. According to the DEM (Myerson et al., 2003), the intercept of the regression on the diagonal (asterisk) marks the sensorimotor component of the response (invariant across groups)

– According to the DEM (Myerson et al., 2003), the intercept of the regression on the diagonal represents an estimate of the peripheral sensory-motor compartment; note that, as expected, the observed value (394.8 ms) is similar to that of the means-SDs plot, as predicted by the DEM (Myerson et al., 2003).
– The slope of the linear regression (2.47) indicates a rather severe impairment, i.e., that the cognitive part of the response is delayed 2.47 times in adults with dyslexia compared to controls.

Comment

The results indicate a clear presence of global components in the data, consistent with the predictions of the DEM (Myerson et al., 2003). Further, the empirical parameters observed (in terms of the slope of the linear regression of the Brinley plot and the intercept marking the sensorimotor component of the response) are broadly in keeping with previous observations on reading (Zoccolotti et al., 2018). These observations support the interest in evaluating the influence of the psycholinguistic parameters by controlling the expected over-additivity effect using an individually based z-score transformation as envisaged by Faust et al. (1999). Further comments on global components will be presented in the Discussion.

Test of psycholinguistic variables

The results of the linear mixed-effects model showed the significance of the main effect of the group factor, $Fr\,(1,50)=82.02$, $p<0.001$): participants with dyslexia had longer vocal RTs than the control group (mean RTs = 744 and 535 ms, respectively; diff. = -209). In the analysis with z-transformed scores, the group variable was insignificant in keeping with the data transformation.

Several psycholinguistic factors proved significant:

- The main effect of length, $Fr\,(1,638)=202.02$, $p<0.001$; $Fz\,(1,638)=157.52$; $p<0.001$, indicated that RTs slowed as a function of word length: on average short words (1st tertile of the word length distribution) were read in 616 ms, medium length words (2nd tertile) in 640 ms, and long words (3rd tertile) in 663 ms.
- The main effect of word frequency was significant, $Fr\,(1,619.6)=37.75$, $p<0.001$; $Fz\,(1,621)=26.05$, $p<0.001$. Reading RTs decreased as a function of word frequency: on average, low-frequency words (1st tertile of the word frequency distribution) were read in 653 ms., medium-frequency words (2nd tertile) in 640 ms and high-frequency words (3rd tertile) in 626 ms.
- The N-size factor was insignificant in either the raw data, $Fz\,(1,10491)=0.23$, n.s., or the z-transformed data, $Fz\,(1,10491)=0.20$, n.s.
- The effect of the contextual rules factor was significant in the analysis with z-transformed data, $Fz\,(1,11223)=4.44$, $p=0.035$; however, the effect was insignificant in the raw data analysis.

The analyses also showed several interactions between group and psycholinguistic factors. The group factor interacted with length in the raw data analyses, $Fr\,(1,$

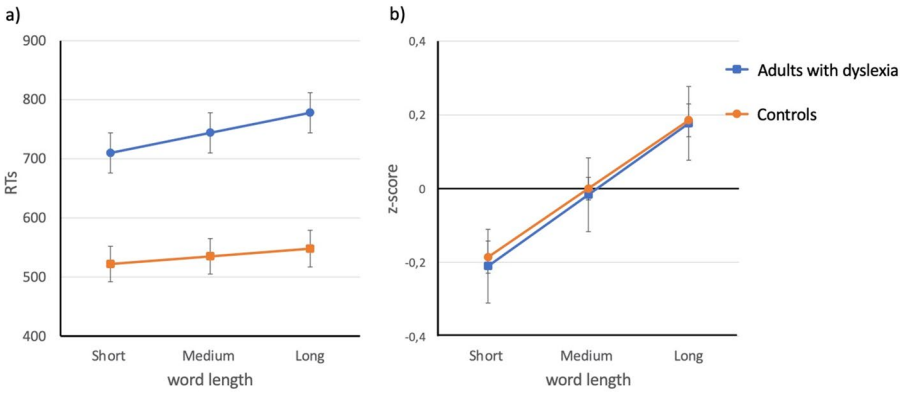

Fig. 3 Group by length interaction. **A**) Raw RT data; **b**) Z-transformed data. Error bars indicate 95% confidence limits

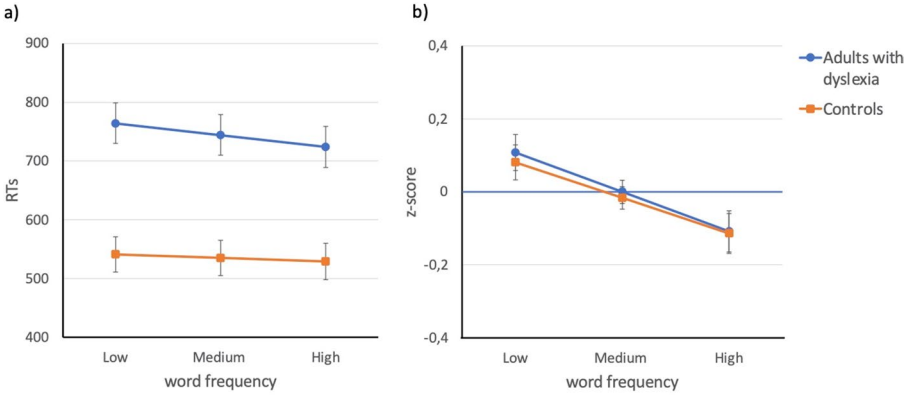

Fig. 4 Group by frequency interaction. **A**) Raw RT data; **b**) Z-transformed data. Error bars indicate 95% confidence limits

31538.8) = 191.24, $p < 0.001$: RTs of participants with dyslexia were more affected by length than controls (Fig. 3a). However, the effect was not significant in the analyses with z-transformed data, $Fz < 1$; n.s., indicating that the interaction in the raw data was due to the influence of over-additivity (Fig. 3b).

The group-by-word frequency interaction was significant, Fr (1,31300.5) = 51.08, $p < 0.001$: word frequency influenced RTs more in the dyslexic group than in the control group. Participants with dyslexia read high-, medium-, and low-frequency stimuli with RTs increasing by 20 ms as a function of word frequency. This increase was smaller in the control group, whose RTs grew by 6 ms moving from high- to medium- and low-frequency stimuli (Fig. 4a). The interaction disappeared in the analysis of z-transformed data, $Fz < 1$; n.s., indicating that it was due to over-additivity in the data (Fig. 4b).

A significant interaction was also observed among group, length, and word frequency, Fr (2,1231.1) = 12.07; $p < 0.001$; Fz (2,1228) = 4.29; $p = 0.014$. For both

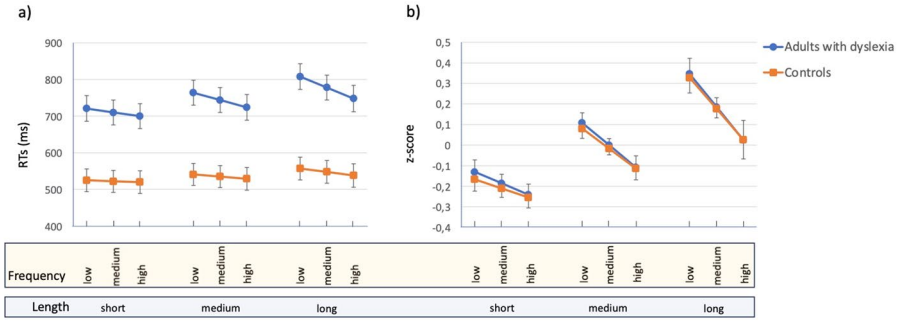

Fig. 5 Group by length by frequency interaction. **A**) Raw RT data; **b**) Z-transformed data. Error bars indicate 95% confidence limits

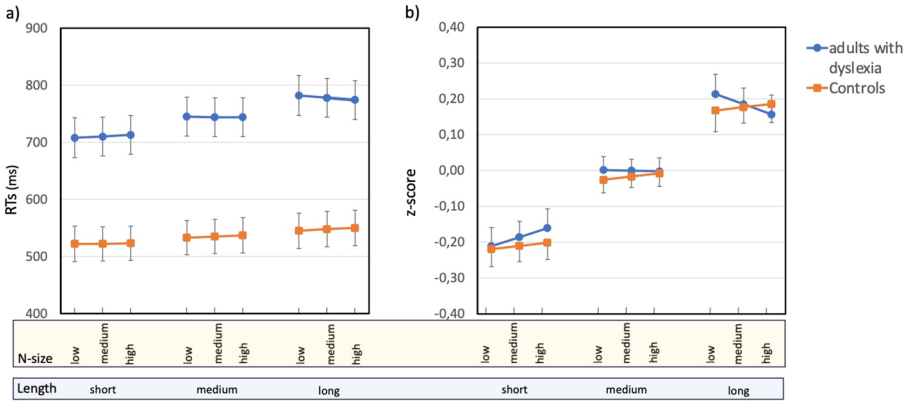

Fig. 6 Group by length by N-size interaction. **A**) Raw RT data; **b**) Z-transformed data. Error bars indicate 95% confidence limits

groups, the effect of frequency was progressively stronger the longer the word stimulus, an effect that can be appreciated both in the raw (Fig. 5a) and in the z-transformed (Fig. 5b) data. In the raw data, the effect of both length and frequency were quantitatively greater in adults with dyslexia; in the z-transformed data, the two groups were similar except for the short word stimuli, for which the effect of frequency was more marked in adults with dyslexia.

The group by N-size interaction was insignificant in the raw RT, $Fz = 1.5$; n.s., and the z-transformed data, $Fz < 1$; n.s., analyses. However, the effect of N-Size was apparent in interaction with length. Thus, the group factor interacted with word length and N-Size in the z-transformed data analysis, $Fz\ (2,22935) = 3.05$; $p = 0.04$, while in the analysis of raw data, this interaction fell short of significance, $Fr\ (1,16384.2) = 2.79$; $p = 0.06$ (Fig. 6a and b). In adults with dyslexia, there was a facilitatory effect of a dense N-size limited to long words. This effect can be appreciated more clearly in the z-transformed data (Fig. 6b). Controls showed no clear impact of N-size independent of word length.

Group interacted with contextual rules, *Fz* (1,31431)=13.86; $p<0.001$, in the z-transformed data analysis but not in the raw RT data analysis, $Fz<1$; n.s. This interaction was qualified by the higher-order interaction group by length by contextual rules. This was significant for both raw, *Fr* (2,11424.4)=3.74; $p=0.02$ and z-transformed data, *Fz* (2,17603)=3.803; $p=0.02$: the presence of contextual rules influenced the reading speed of long words in the control group; this effect was not observed in adults with dyslexia, who exhibited longer RTs for the reading of long stimuli regardless of the presence or absence of contextual rules (Fig. 7).

All other interactions between psycholinguistic variables and the group factor were not significant. The random effects of items and participants were significant ($p<0.001$).

Test of psycholinguistic variables: stress assignment

The additional mixed-effects model conducted to investigate the role of stress type on words with more than two syllables showed the significance of the group effect, *Fr* (1,50.5)=88.97, $p<0.001$, with adults with dyslexia exhibiting longer RTs compared to controls (mean RTs=757 and 538 ms, respectively; diff. = -219). Due to data transformation, the group factor was not significant in the analysis of z-transformed data, $Fz<1$; n.s.

The analysis showed the main effects of stress type, *Fr* (1,618.9)=15.08, $p<0.001$; *Fz* (1,621)=12.65; $p<0.001$, with words with penultimate stressed syllable being read faster than words with an antepenultimate stressed syllable, and word frequency, *Fr* (1,619.2)=19.68, $p<0.001$; *Fz* (1,343)=15.99, $p<0.001$, with higher frequency stimuli read more quickly than lower frequency ones.

The group interacted with stress type both in the raw data, *Fr* (1,30964)=35.66; $p<0.001$, and in the z-transformed data model, *Fz* (1,343)=8.67, $p<0.005$, with adults with dyslexia showing slower performance in reading stimuli with antepenultimate stressed syllables (see Fig. 8).

The model also highlighted a significant interaction between the group and word frequency, *Fr* (1,30958)=63.77; $p<0.001$, with adults with dyslexia showing greater

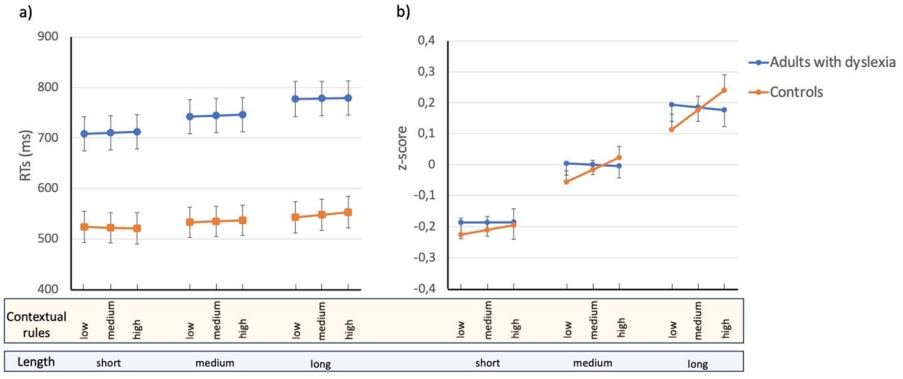

Fig. 7 Group by length by contextual rules interaction. **A**) Raw RT data; **b**) Z-transformed data. Error bars indicate 95% confidence limits

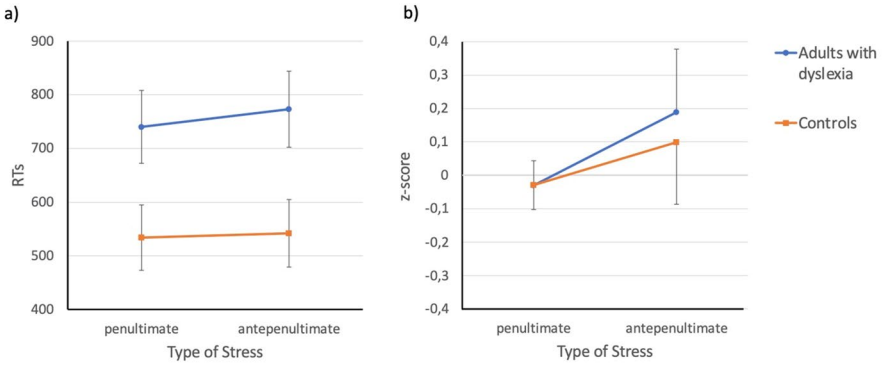

Fig. 8 Group by stress type interaction. **A**) Raw RT data; **b**) Z-transformed data. Error bars indicate 95% confidence limits

facilitation in reading frequent stimuli than controls. However, this interaction was not present in the z-transformed data analysis, Fz (1,31010)<1, n.s., indicating over-additivity.

The group by stress by word frequency interaction was significant, Fr (12,1214.7)=6.94, p=0.001, indicating how the frequency variable modulates the stress effect: participants with dyslexia read antepenultimate stressed words of low frequency more slowly than controls, and this difference was smaller with higher frequency stimuli; however, this result was not reflected in the analysis with z-transformed data, Fr (12,1218)=2.76, p=0.06.

Computation of the absolute RTs difference between groups

As stated in the analyses on global components, we estimated that adults with dyslexia were delayed 2.47 times compared to controls. However, in keeping with the DEM (Myerson et al., 2003) this estimate refers only to the cognitive part of response. By contrast, the model envisages that the sensorimotor component (here estimated to be ca. 400 ms.) will not differ between the two groups of subjects. Thus, an interesting question concerns estimating the overall difference in raw data (which cumulate sensorimotor and cognitive components) between the two groups of subjects.

In previous work (Zoccolotti et al., 2015), we re-analysed several studies of RTs to word recognition in Italian children with and without a reading deficit. The overall sample involved 331 typically developing children and 172 children with dyslexia. Across studies, the mean performance of typically developing children read on average in 602.5 ms (SD=82.6.2) while children with dyslexia in 891.7 (SD=265.3). Notably, these, and other related data violate the homogeneity of variance, with children with dyslexia considerably more variable than control children. Based on this consideration, we proposed that, in the case of raw RT data, a more appropriate measure of effect size is the ratio (Zoccolotti et al., 2015). Across studies, the obtained ratio was 1.47. Table 2 summarises these data together with the data from adult subjects of the present study. Adults were generally faster than children, an effect present both in controls and adults with dyslexia, in keeping with the idea that reading speed

Table 2 Means (and SDs) of vocal RTs to single word recognition. Data on children derive from the re-analysis of Zoccolotti et al. (2015) - data on adults from the present study

	Controls		Individuals with dyslexia			
	Mean	SD	Mean	SD	Diff.	Ratio
Children	602.5	82.6	891.7	265.3	289.2	1.47
Adults	535		744		209	1.39
Difference	67.5		147.7			

progresses well beyond primary and middle school (Carver, 1992; Brysbaert, 2019). However, it may be noted that the ratio between adults with dyslexia and controls in the present sample is very similar to that obtained with children, a finding in keeping with the stability of the reading deficit.

Discussion

As expected, adults with dyslexia showed a general slowing compared to control readers. This slowing was well described by a single global factor closely in keeping with the predictions of the DEM model (Myerson et al., 2003). Indeed, the variance accounted for by this factor was well above 90%, highlighting a robust role of this global component in the reading of adults with dyslexia. Thus, this finding suggests that the influence of a global factor extends beyond the early stages of reading acquisition and persists even after years of practice among individuals who have pursued higher education. Evidence indicates that this global component may have an even stronger impact on adults with dyslexia compared to children. First, the variance accounted for by the global factor is particularly high. Second, to preview the results discussed in more detail below, the presence of residual effects (after controlling for over-additivity) is somewhat smaller in adults with dyslexia compared to children.

In the previous research on children, we tried to qualify the nature of this global effect. As stated in the introduction, the fact that a group of individuals behaves consistently across several different conditions does not automatically entail that such slowness will apply across all conditions (Myerson et al., 2003). Thus, we observed that children with dyslexia are consistently delayed when they must read words and nonwords presented visually. However, they are not (or minimally) impaired when they must name pictures (Zoccolotti et al., 2008; De Luca et al., 2017), when the task involves only one or two letters (De Luca et al., 2010), or when the presentation of words (and nonwords) occurs in the auditory modality (Marinelli et al., 2011). Accordingly, we have proposed (e.g., De Luca et al., 2017) that individuals with dyslexia show a selective difficulty in forming a pre-lexical representation of the orthographic string (also called "*graphemic description*" by Marsh & Hillis, 2005). The present results are in keeping with the idea that this nuclear deficit of dyslexia is quite stable over the years despite prolonged exposure to print and reading experience.

Models, such as the DEM, allow teasing out the sensorimotor and cognitive components of the response which may be instrumental in interpreting the reading disorder. However, looking at absolute RT differences (which cumulate sensorimotor and cognitive components) is also informative. As expected, adults with dyslexia showed

a general slowing compared to control readers of ca. 200 ms., indicating an approximate delay of 40% (or a ratio of 1.39). This figure is similar to that observed across various studies with Italian children with and without a reading deficiency (i.e., a 1.47 ratio; Zoccolotti et al., 2015). Thus, reading slowing holds through adult age even in students admitted to college for whom general stimulation and substantial reading practice are expected. The RTs of the present sample of adult (skilled and dyslexic) subjects were faster than those of younger children on similar (though not identical) tasks/stimuli. This observation aligns with the idea that reading times continue to evolve throughout the lifespan for both skilled and impaired readers (Carver, 1992; Brysbaert, 2019). However, improvements tend to become progressively smaller (in absolute values), as predicted by a power function trend (Zoccolotti et al., 2009).

Vocal RT data confirmed the influence of several psycholinguistic variables, including frequency, length, and stress type. As expected, these factors affected students with dyslexia more than controls. For example, RTs increased by ca. 20 ms, passing from high- to medium- and low-frequency stimuli in adults with dyslexia, while the corresponding increase was ca. 6 ms in control readers. When data were analysed in terms of z-transformed values, this difference disappeared indicating that the differences between the two groups of subjects were entirely due to an over-additivity effect, i.e., to the tendency of the slower group to show larger effects over and above the specific influence of a given experimental condition. This finding is consistent with previous observations on younger children (Paizi et al., 2013).

A similar pattern was observed in the case of length. Again, the influence of this variable was significantly stronger in adults with dyslexia compared to controls. However, this group interaction disappeared when analysing z-transformed values. This finding is at variance with previous observations on children where a residual specific effect of length was observed (Zoccolotti et al., 2008; De Luca et al., 2010). Therefore, after several years of practice, only the overall difference between the two groups determines the performance; the differential effect of length in the two groups is no longer an expression of a specific effect.

Frequency and length also interacted, with the effect of frequency being more pronounced for longer words. In the raw data analysis, the adults with dyslexia exhibited more pronounced length and frequency effects. In the z-transformed data analysis, this interaction remained significant, suggesting a slight tendency for adults with dyslexia to show a stronger frequency effect for high-frequency words.

It is generally acknowledged that dense N-size tends to be associated with faster RTs, i.e., to have a facilitatory effect (Andrews, 1997; Carreiras et al., 1997). We did not observe a main effect of N-size. Thus, when examining a large set of words varying along various psycholinguistic parameters, N-size does not exert a detectable influence. There are only a few studies examining this parameter in Italian observers. Marinelli et al. (2013) reported that RTs of children with dyslexia were faster for words with dense N-size than for words with sparse N-size, the effect being more pronounced for low-frequency words. The authors proposed that spreading activation from dense N-size facilitated word recognition in children with dyslexia, indicating spared lexical processing in these children. Interestingly, in that study control children showed limited and non-significant influence of N-size; the lack of facilitation was presumably due to the already high level of performance for the target stim-

uli. Evidence of N-size influence on the reading of children with dyslexia was also reported in Dutch children (Marinus & de Jong, 2010). In the present study, students with dyslexia showed a facilitatory effect of dense N-size limited to long stimuli. This interaction with length was unexpected. As mentioned above, we anticipated an interaction with frequency, which was not observed. One possible hypothesis is that the facilitatory effect of a dense N-size becomes more evident with more challenging stimuli, such as longer words. These stimuli require longer processing times, allowing more opportunity for spreading activation processes. Overall, the observed effect of N-size suggests that adults with dyslexia benefit from the spreading lexical activation provided by a dense neighbourhood. This is consistent with a previous single-case study that reported preserved orthographic activation in an adult with dyslexia (Lavidor et al., 2006). Since the interaction between neighbourhood size and length was unexpected, it will be important to confirm this finding in future studies on adults with dyslexia.

Another significant interaction involved the influence of contextual rules. In Italian, the pronunciation of sequences with letters c and g is determined by complex, context-sensitive rules that depend on the letters that follow them. Previous evidence indicates that both adult observers (Burani et al., 2006) and children (Barca et al., 2007) exhibit slower responses when encountering words that contain these context-sensitive rules, particularly when it comes to low-frequency words. This pattern is believed to be due to the activation of sublexical procedures (Burani et al., 2006). In the current data set, contextual rules negatively influenced latencies in interaction with word length and participant group. The effect was more pronounced with longer words and was observed only among control participants, not among adults with dyslexia. This finding differs from previous evidence, as the moderating effect of contextual rules was related to word length rather than frequency. Furthermore, adults with dyslexia did not display this effect, contrary to what was previously observed in children (Barca et al., 2007), possible because they were already too slow in the condition with few or no contextual rules. Therefore, this unexpected finding highlights the need for further confirmation in future research.

Finally, we examined stress assignment on a subset of words with at least three syllables. Data revealed that words with stress on the penultimate syllable were read faster than those with stress on the antepenultimate syllable in both groups. However, adults with dyslexia exhibited notably slower performance with antepenultimate-stressed words, an effect that remained significant in the z-transformed data analysis. This pattern indicates a genuine group difference that cannot be attributed to an over-additivity effect.

Overall, these data indicate that adults with dyslexia are sensitive to the lexical quality of the stimulus. However, this finding does not necessarily exclude the presence of lexical deficiencies. In a recent study on adults with dyslexia, Nardacchione et al. (2024) using a different experimental paradigm identified a potential deficit in lexical expansion, indicating that individuals with dyslexia may have fewer orthographic representations in their lexicon than typically developing readers.

Study limitations

Some limitations of the examined sample of adults with dyslexia should be underscored. We noted that only some received a previous diagnosis, a phenomenon which has already been described (e.g., Barbiero et al., 2019), although it is probably diminishing in the last years because of the introduction of clinical guidelines from the Italian Superior Institute of Health (ISS, 2011; Progetto LG-DSA, 2021). There were not enough participants to test whether the presence/absence of a clinical diagnosis was associated with a different profile of responding. At any rate, all participants were retested at admission to the college, making the data comparable. In view of the specificities of the sample and its moderate size, it will be relevant to confirm the present data on a larger and, possibly more homogeneous, sample.

Conclusions

Overall, data from a group of adults with dyslexia indicate that their reading RTs are largely explained by a global factor that accounts for over 90% of individual variance. Based on previous research, we have proposed that this factor reflects a selective difficulty in forming a pre-lexical representation of the orthographic string, which affects all (and only) tasks requiring such processing, such as reading. Despite prolonged exposure to print and extensive reading experience, college students with dyslexia still exhibit significant deficits in this type of processing.

The examination of psycholinguistic variables generally confirmed that individuals with dyslexia were sensitive to the lexical quality of stimuli, such as frequency effects. These effects were comparable to those observed in control subjects once over-additivity was controlled using intra-individual z-scores. However, a few specific differences emerged. Adults with dyslexia were more sensitive than controls to the N-size, particularly to longer stimuli. This finding parallels results observed in children, although the unexpected association with length warrants further investigation. Additionally, adults with dyslexia showed a selective deficiency for words stressed on the antepenultimate syllable.

Overall, the influence of psycholinguistic parameters was somewhat smaller than in children. For example, no residual effect of length was observed after controlling for over-additivity, which is often noted in children. Thus, it can be concluded that the global deficit -manifested as difficulty in forming a pre-lexical representation of the orthographic string- has a prominent influence on the reading performance of college students with developmental dyslexia.

Acknowledgements This research was funded by the MIUR Progetti di Rilevante Interesse Nazionale (PRIN) Bando 2022– "Clinical markers of linguistic and literacy vulnerabilities in adulthood: it's never too late!" (Grant 20229PSYEP, DD n. 1016 SH4 del 7/7/2023) awarded to P.A. and C.V.M. (CUP: F53D23004680006). Additional funding was provided by the MIUR PRIN Bando 2022 (Grant 20229PSYEP) to P.A. and C.V.M., as well as by the AUTO-ReSpeMa project (CUP: F53D23011220001), funded by the EU under the NextGenerationEU plan through the Italian "Bando PRIN 2022 - D.D. 1409 del 14-09-2022," awarded to M.T. and C.V.M.

Author contributions Conceptualization, F.V., P.Z, C.V.M, P.A.; methodology, F.V., P.Z., C.V.M, P.A; formal analysis, F.V., C.V.M; investigation, F.V., M.I. and P.A.; data curation, F.V., C.V.M, M.I., P.Z. and P.A.; writing—original draft preparation, F.V., C.V.M, P.Z. and P.A.; writing—review and editing, F.V., P.Z., C.V.M., P.A., M.I., M.D.C. and M.T.; funding acquisition, P.A, C.V.M. and M.T. All authors have read and agreed to the published version of the manuscript.

Funding Open access funding provided by Università del Salento within the CRUI-CARE Agreement.

Declarations

Institutional Review Board Statement The study was conducted in accordance with the Declaration of Helsinki and approved by Ethics Committee for Research in Psychology of the DiSUS and by the Data Protection Officer (DPO) of the University of Salento (protocol code: 71084; date of approval: 5 May 2021).

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

References

Afonso, O., Suárez-Coalla, P., & Cuetos, F. (2015). Spelling impairments in Spanish dyslexic adults. *Frontiers in Psychology*, *6*, 466. https://doi.org/10.3389/fpsyg.2015.00466

Andrews, S. (1997). The effect of orthographic similarity on lexical retrieval: Resolving neighborhood conflicts. *Psychonomic Bulletin & Review*, *4*, 439–461. https://doi.org/10.3758/BF03214334

Angelelli, P., Marinelli, C. V., & Zoccolotti, P. (2010). Single or dual orthographic representations for reading and spelling? A study on Italian dyslexic and dysgraphic children. *Cognitive Neuropsychology*, *27*, 305–333. https://doi.org/10.1080/02643294.2010.543539

Barbiero, C., Montico, M., Lonciari, I., Monasta, L., Penge, R., Vio, C., Tressoldi, P. E., Carrozzi, M., De Petris, A., De Cagno, A. G., Crescenzi, F., Tinarelli, G., Leccese, A., Pinton, A., Belacchi, C., Tucci, R., Musinu, M., Tossali, M. L., Antonucci, A. M., & Ronfani, L. (2019). The lost children: The underdiagnosis of dyslexia in Italy. A cross-sectional national study. *PLoS ONE*, *14*(1), e0210448. https://doi.org/10.1371/journal.pone.0210448

Barca, L., Burani, C., & Arduino, L. S. (2002). Word naming times and psycholinguistic norms for Italian nouns. *Behavior Research Methods Instruments & Computers*, *34*, 424–434. https://doi.org/10.3758/BF03195471

Barca, L., Burani, C., Di Filippo, G., & Zoccolotti, P. (2006). Italian developmental dyslexic and proficient readers: Where are the differences? *Brain and Language*, *98*(3), 347–351. https://doi.org/10.1016/j.bandl.2006.05.001

Barca, L., Ellis, A. W., & Burani, C. (2007). Context-sensitive rules and word naming in Italian children. *Reading and Writing*, *20*, 495–509. https://doi.org/10.1007/s11145-006-9040-z

Bonin, P., Méot, A., & Bugaiska, A. (2018). Concreteness norms for 1,659 French words: Relationships with other psycholinguistic variables and word recognition times. *Behavior Research Methods*, *50*, 2366–2387. https://doi.org/10.3758/s13428-018-1014-y

Borgonovi, E., Comellini, F. A., Ferrucci, F., Mason, L., Migliaccio, G., Scaletta, A., & Tanucci, G. (2022). *Gli studenti con disabilità e DSA nelle università italiane. Una risorsa da valorizzare* [Students with disabilities and learning disorders in Italian universities: A resource to be valued]. ANVUR. https://www.anvur.it/wp-content/uploads/2022/06/ANVUR-Rapporto-disabilita_WEB.pdf

Breznitz, Z. (2002). Asynchrony of visual–orthographic and auditory–phonological word recognition processes: An underlying factor in dyslexia. *Reading and Writing*, *15*, 15–42. https://doi.org/10.1023/A:1013864203452

Bruck, M. (1990). Word recognition skills of adults with childhood diagnoses of dyslexia. *Developmental Psychology*, *26*, 439–454. https://doi.org/10.1037/0012-1649.26.3.439

Brysbaert, M. (2019). How many words do we read per minute? A review and meta-analysis of reading rate. *Journal of Memory and Language*, *109*, 104047. https://doi.org/10.1016/j.jml.2019.104047

Burani, C., & Arduino, L. S. (2004). Stress regularity or consistency? Reading aloud Italian polysyllables with different stress patterns. *Brain and Language*, *90*(1–3), 318–325. https://doi.org/10.1016/S0093-934X(03)00444-9

Burani, C., Barca, L., & Ellis, A. W. (2006). Orthographic complexity and word naming in Italian: Some words are more transparent than others. *Psychonomic Bulletin & Review*, *13*, 346–352. https://doi.org/10.3758/BF03193855

Burani, C., Arduino, L. S., Marinelli, C. V., & Barca, L. (2015). Variabili lessicali e sublessicali-2: Valori per 626 nomi dell'italiano. https://www.istc.cnr.it/it/grouppage/varless

Carioti, D., Masia, M. F., Travellini, S., & Berlingeri, M. (2021). Orthographic depth and developmental dyslexia: A meta-analytic study. *Annals of Dyslexia*, *71*(3), 399–438. https://doi.org/10.1007/s11881-021-00226-0

Carreiras, M., Perea, M., & Grainger, J. (1997). Effects of the orthographic neighborhood in visual word recognition: Cross-task comparisons. *Journal of Experimental Psychology: Learning Memory and Cognition*, *23*(4), 857–871. https://doi.org/10.1037/0278-7393.23.4.857

Carver, R. P. (1992). Reading rate: Theory, research, and practical implications. *Journal of Reading*, *36*(2), 84–95. https://www.jstor.org/stable/40016440

Caspi, A., Entner Wright, B. R., Moffitt, T. E., & Silva, P. A. (1998). Early failure in the labor market: Childhood and adolescent predictors of unemployment in the transition to adulthood. *American Sociological Review*, *63*, 424–451. https://doi.org/10.2307/2657557

Colombo, L. (1992). Lexical stress effect and its interaction with frequency in word pronunciation. *Journal of Experimental Psychology: Human Perception and Performance*, *18*(4), 987. https://doi.org/10.1037/0096-1523.18.4.987

Conti-Ramsden, G., Durkin, K., Simkin, Z., & Knox, E. (2009). Specific language impairment and school outcomes. I: Identifying and explaining variability at the end of compulsory education. *International Journal of Language & Communication Disorders*, *44*(1), 15–35. https://doi.org/10.1080/13682820801921601

Corkett, J. K., & Parrila, R. (2008). Use of context in the word recognition process by adults with a significant history of reading difficulties. *Annals of Dyslexia*, *58*(2), 139–161. https://doi.org/10.1007/s11881-008-0018-1

De Luca, M., Barca, L., Burani, C., & Zoccolotti, P. (2008). The effect of word length and other sublexical, lexical and semantic variables on developmental reading deficit. *Cognitive and Behavioral Neurology*, *21*, 227–235. https://doi.org/10.1097/WNN.0b013e318190d162

De Luca, M., Burani, C., Paizi, D., Spinelli, D., & Zoccolotti, P. (2010). Letter and letter-string processing in developmental dyslexia. *Cortex; A Journal Devoted To the Study of the Nervous System and Behavior*, *46*(10), 1272–1283. https://doi.org/10.1016/j.cortex.2009.06.007

De Luca, M., Marinelli, C. V., Spinelli, D., & Zoccolotti, P. (2017). Slowing in reading and picture naming: The effects of aging and developmental dyslexia. *Experimental Brain Research*, *235*, 3093–3109. https://doi.org/10.1007/s00221-017-5041-1

Eloranta, A. K., Närhi, V. M., Eklund, K. M., Ahonen, T. P., & Aro, T. I. (2019). Resolving reading disability—Childhood predictors and adult-age outcomes. *Dyslexia*, *25*(1), 20–37. https://doi.org/10.1002/dys.1605

Faust, M. E., Balota, D. A., Spieler, D. H., & Ferraro, F. R. (1999). Individual differences in information-processing rate and amount: Implications for group differences in response latency. *Psychological Bulletin*, *125*, 777–799. https://doi.org/10.1037/0033-2909.125.6.777

Gerber, P. J. (2012). The impact of learning disabilities on adulthood: A review of the evidenced-based literature for research and practice in adult education. *Journal of Learning Disabilities*, *45*(1), 31–46. https://doi.org/10.1177/0022219411426858

Goulandris, N. (2003). *Dyslexia in Different Languages: Cross-linguistic Comparisons*. Whurr.

Hatcher, J., Snowling, M. J., & Griffiths, Y. M. (2002). Cognitive assessment of dyslexic students in higher education. *British Journal of Educational Psychology*, *72*(1), 119–133. https://doi.org/10.1348/000709902158801. high-functioning adult dyslexics *Dyslexia*, 15(2), 105–128. https://doi.org/10.1002/dys.364

Iaia, M., Vizzi, F., D. Carlino, M., Turi, M., V. Marinelli, C., & Angelelli, P. (2024). Specific learning disabilities and associated emotional-motivational profiles: A study in Italian university students. *ArXiv*. https://doi.org/10.31234/osf.io/8vwat

ISS– Istituto Superiore di Sanità (2011). *Consensus Conference. Disturbi Specifici dell'Apprendimento*. (Eng. Transl.: Consensus Conference. Specific Learning Disorders). National System for Guidelines, Department of Health, Rome.

Judica, A., Luca, M. D., Spinelli, D., & Zoccolotti, P. (2002). Training of developmental surface dyslexia improves reading performance and shortens eye fixation duration in reading. *Neuropsychological Rehabilitation*, *12*(3), 177–197. https://doi.org/10.1080/09602010244000002

Kemp, N., Parrila, R. K., & Kirby, J. R. (2009). Phonological and orthographic spelling in.

Lavidor, M., Johnston, R., & Snowling, M. J. (2006). When phonology fails: Orthographic neighbourhood effects in dyslexia. *Brain and Language*, *96*(3), 318–329. https://doi.org/10.1016/j.bandl.2005.06.009

Lefly, D. L., & Pennington, B. F. (1991). Spelling errors and reading fluency in compensated adult dyslexics. *Annals of Dyslexia*, *41*, 143–162. https://doi.org/10.1007/BF02648083

Marinelli, C. V., Angelelli, P., Notarnicola, A., et al. (2009). Do Italian dyslexic children use the lexical reading route efficiently? An orthographic judgment task. *Reading and Writing*, *22*, 333–351. https://doi.org/10.1007/s11145-008-9118-x

Marinelli, C. V., Angelelli, P., Di Filippo, G., & Zoccolotti, P. (2011). Is developmental dyslexia modality specific? A visual-acoustic comparison on Italian dyslexics. *Neuropsychologia*, *49*, 1718–1729. https://doi.org/10.1016/j.neuropsychologia.2011.02.050

Marinelli, C. V., Traficante, D., Zoccolotti, P., & Burani, C. (2013). Orthographic neighborhood-size effects on the reading aloud of Italian children with and without dyslexia. *Scientific Studies of Reading*, *17*(5), 333–349. https://doi.org/10.1080/10888438.2012.723080

Marinelli, C. V., Traficante, D., & Zoccolotti, P. (2014). Does pronounceability modulate the letter string deficit of children with dyslexia? Evidence from lexical decision task. *Frontiers in Psychology*, *5*, 1353. https://doi.org/10.3389/fpsyg.2014.01353

Marinelli, C. V., Zoccolotti, P., & Romani, C. (2020). The ability to learn new written words is modulated by Language orthographic consistency. *PLoS One*, *15*(2), e0228129. https://doi.org/10.1371/journal.pone.0228129

Marinus, E., & de Jong, P. F. (2010). Size does not matter, frequency does: Sensitivity to orthographic neighbors in normal and dyslexic readers. *Journal of Experimental Child Psychology*, *106*(2–3), 129–144. https://doi.org/10.1016/j.jecp.2010.01.004

Marsh, E. B., & Hillis, A. E. (2005). Cognitive and neural mechanisms underlying reading and naming: Evidence from letter-by-letter reading and optic aphasia. *Neurocase*, *11*, 325–337. https://doi.org/10.1080/13554790591006320

Martelli, M., De Luca, M., Lami, L., Pizzoli, C., Pontillo, M., Spinelli, D., & Zoccolotti, P. (2014). Bridging the gap between different measures of the reading speed deficit in developmental dyslexia. *Experimental Brain Research*, *232*, 237–252. https://doi.org/10.1007/s00221-013-3735-6

Maughan, B., Messer, J., Collishaw, S., Pickles, A., Snowling, M., Yule, W., & Rutter, M. (2009). Persistence of literacy problems: Spelling in adolescence and at mid-life. *Journal of Child Psychology and Psychiatry*, *50*(8), 893–901. https://doi.org/10.1111/j.1469-7610.2009.02079.x

McLaughlin, M., Speirs, K. E., & Shenassa, E. D. (2014). Reading disability and adult attained education and income: Evidence from a 30-year longitudinal study of a population-based sample. *Journal of Learning Disabilities*, *47*, 374–386. https://doi.org/10.1177/0022219412458323

Miller-Shaul, S. (2005). The characteristics of young and adult dyslexics readers on reading and reading related cognitive tasks as compared to normal readers. *Dyslexia*, *11*(2), 132–151. https://doi.org/10.1002/dys.290

Montesano, L., Valenti, A., & Cornoldi, C. (2020). *LSC-SUA. Prove di lettura, comprensione del testo, scrittura e calcolo. Batteria per la valutazione dei DSA e altri disturbi in studenti universitari e adulti* (Eng. Trans.: Tests of reading, text comprehension, writing, and computation. Battery for the assessment of DSA and other disorders in college students and adults) (Vol. 1, No. 1, 2, 3, 4, pp. 1-181). Trento: Erickson.

Myerson, J., Hale, S., Zheng, Y., Jenkins, L., & Widaman, K. F. (2003). The difference engine: A model of diversity in speeded cognition. *Psychonomic Bulletin & Review*, *10*, 262–288. https://doi.org/10.3758/BF03196491

Nardacchione, G., Zoccolotti, P., Angelelli, P., Vizzi, F., & Marinelli, C. V. Lexical processing and sensitivity to statistical distributional properties in adults with developmental dyslexia. Ann. Dyslexia. Manuscript submitted for publication.

Nergård-Nilssen, T., & Hulme, C. (2014). Developmental dyslexia in adults: Behavioural manifestations and cognitive correlates. *Dyslexia*, *20*(3), 191–207. https://doi.org/10.1002/dys.1477

Olofsson, Å., Taube, K., & Ahl, A. (2015). Academic achievement of university students with dyslexia. *Dyslexia*, *21*(4), 338–349. https://doi.org/10.1002/dys.1517

Orsini, A., & Pezzuti, L. (2013). *WAIS-IV: Contributo alla taratura italiana (16–69 anni).* Giunti OS.

Paizi, D., De Luca, M., Burani, C., & Zoccolotti, P. (2011a). List context manipulation reveals orthographic deficits in Italian readers with developmental dyslexia. *Child Neuropsychology*, *17*, 459–482. https://doi.org/10.1080/09297049.2010.551187

Paizi, D., Zoccolotti, P., & Burani, C. (2011b). Lexical stress assignment in Italian developmental dyslexia. *Reading and Writing*, *24*, 443–461. https://doi.org/10.1007/s11145-010-9236-0

Paizi, D., De Luca, M., Zoccolotti, P., & Burani, C. (2013). A comprehensive evaluation of lexical reading in Italian developmental dyslexics. *Journal of Research in Reading*, *36*, 303–329. https://doi.org/10.1111/j.1467-9817.2011.01504.x

Progetto, L. G. D. S. A. (2021). *Linea Guida per la gestione dei Disturbi Specifici di Apprendimento. Aggiornamento ed integrazioni* (Eng. Transl.: Guideline for the Management of Specific Learning Disorders. Update and additions). Rome (approved by the National System for Guidelines in January 2022).

Reis, A., Araújo, S., Morais, I. S., & Faísca, L. (2020). Reading and reading-related skills in adults with dyslexia from different orthographic systems: A review and meta-analysis. *Annals of Dyslexia*, *70*, 339–368. https://doi.org/10.1007/s11881-020-00205-x

Scorza, M., Gontkovsky, S. T., Puddu, M., Ciaramidaro, A., Termine, C., Simeoni, L., & Benassi, E. (2023). Cognitive profile discrepancies among typical university students and those with dyslexia and mixed-type learning disorder. *Journal of Clinical Medicine*, *12*(22), 7113. https://doi.org/10.3390/jcm12227113

Shaywitz, S. E., Fletcher, J. M., Holahan, J. M., Schneider, A. E., Marchione, K. E., Stuebing, K. K., et al. (1999). Persistence of dyslexia: The connecticut longitudinal study at adolescence. *Pediatrics*, *104*(6), 1351–1359. https://doi.org/10.1542/peds.104.6.1351

Spinelli, D., De Luca, M., Di Filippo, G., Mancini, M., Martelli, M., & Zoccolotti, P. (2005). Length effect in word naming in reading: Role of reading experience and reading deficit in Italian readers. *Developmental Neuropsychology*, *27*(2), 217–235. https://doi.org/10.1207/s15326942dn2702_2

Suárez-Coalla, P., & Cuetos, F. (2015). Reading difficulties in Spanish adults with dyslexia. *Annals of Dyslexia*, *65*, 33–51. https://doi.org/10.1007/s11881-015-0101-3

Theiling, J., & Petermann, F. (2016). Neuropsychological profiles on the WAIS-IV of adults with ADHD. *J Atten Disord*, *20*, 913–924. https://doi.org/10.1177/1087054713518241

Tops, W., Callens, M., Stevens, M., & Brysbaert, M. (2020). *Students with dyslexia in higher education: Academic performance and predictors for success*. Department of Experimental Psychology.

Wagenmakers, E. J., & Brown, S. (2007). On the linear relation between the mean and the standard deviation of a response time distribution. *Psychological Review*, *114*, 830–841. https://doi.org/10.1037/0033-295X.114.3.830

Watson, J., & Boman, P. (2005). Mainstreamed students with learning difficulties: Failing and underachieving in the secondary school. *Australian Journal of Learning Difficulties*, *10*(2), 43–49. https://doi.org/10.1080/19404150509546788

Wechsler, D. (2008). *WAIS-IV: Wechsler adult intelligence scale*. Pearson.

Witte, R. H., Philips, L., & Kakela, M. (1998). Job satisfaction of college graduates with learning disabilities. *Journal of Learning Disabilities*, *31*(3), 259–265. https://doi.org/10.1177/002221949803100305

Yap, M. J., & Balota, D. A. (2015). Visual word recognition. In A. PollatsekR.Treiman (Ed.), *The Oxford handbook of reading* (pp. 26–43). Oxford University Press.

Yap, M. J., Balota, D. A., Sibley, D. E., & Ratcliff, R. (2012). Individual differences in visual word recognition: Insights from the english lexicon project. *Journal of Experimental Psychology: Human Perception and Performance*, *38*(1), 53–79. https://doi.org/10.1037/a0024177

Zoccolotti, P., De Luca, M., Di Pace, E., Judica, A., Orlandi, M., & Spinelli, D. (1999). Markers of developmental surface dyslexia in a Language (Italian) with high grapheme-phoneme correspondence. *Applied Psycholinguistics*, *20*(2), 191–216. https://doi.org/10.1017/S0142716499002027

Zoccolotti, P., De Luca, M., Gasperini, F., Judica, A., & Spinelli, D. (2005). Word length effect in early reading and in developmental dyslexia. *Brain and Language*, *93*, 369–373. https://doi.org/10.1016/j.bandl.2004.10.010

Zoccolotti, P., De Luca, M., Judica, A., & Spinelli, D. (2008). Isolating global and specific factors in developmental dyslexia: A study based on the rate and amount model (RAM). *Experimental Brain Research*, *186*, 551–560. https://doi.org/10.1007/s00221-007-1257-9

Zoccolotti, P., De Luca, M., Di Filippo, G., Judica, A., & Martelli, M. (2009). Reading development in an orthographically regular language: Effects of length, frequency, lexicality and global processing ability. *Reading and Writing*, *22*, 1053–1079. https://doi.org/10.1007/s11145-008-9144-8

Zoccolotti, P., De Luca, M., & Spinelli, D. (2015). Discrete versus multiple word displays: A re-analysis of studies comparing dyslexic and typically developing children. *Frontiers in Psychology*, *6*, 1530. https://doi.org/10.3389/fpsyg.2015.01530

Zoccolotti, P., De Luca, M., Di Filippo, G., Marinelli, C. V., & Spinelli, D. (2018). Reading and lexical decision tasks generate different patterns of individual variability as a function of condition difficulty. *Psychonomic Bulletin and Review*, *25*(3), 1161–1169. https://doi.org/10.3758/s13423-017-1335-3

Authors and Affiliations

Francesca Vizzi[1,2] · Chiara Valeria Marinelli[3] · Marika Iaia[2] · Marco Turi[1] · Maria Diletta Carlino[1] · Pierluigi Zoccolotti[4,5] · Paola Angelelli[2]

✉ Paola Angelelli
paola.angelelli@unisalento.it

[1] Department of Human and Social Sciences, Lab of Applied Psychology and Intervention, University of Salento, Lecce, Italy

[2] Department of Experimental Medicine, Lab of Applied Psychology and Intervention, University of Salento, Studium 2000, Edificio 5 V.le San Nicola, Lecce, Italy

[3] Cognitive and Affective Neuroscience Lab, Department of Humanities, University of Foggia, Foggia, Italy

[4] Department of Psychology, Sapienza University of Rome, Rome, Italy

[5] Tuscany Rehabilitation Clinic, Montevarchi, Italy