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A Diagnostic Test for Specific Developmental Dyslexia: A Pilot Study

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Abstract: ***This paper describes the pilot application of a "Dyslexia Test", developed as a comprehensive assessment tool. The test assesses learning difficulties which reflect the main symptoms of SDD in children between 7-12 years. The results showed that [1] the task difficulty index ranged between 76% and 7%, [2] Cronbach's index of the tasks was α=653 and [3] all the sub-tests were found to be strong indicators of the SDD profile. In conclusion, the pilot application of the proposed "Dyslexia Test" diagnostic tool demonstrated a high degree of reliability and validity, rendering the standardization of the test as indispensable for completing this research.***

Keywords: Dyslexia; Memory; Reading; Writing; Grammar

1. Introduction

This study presents the results of the pilot application of a new diagnostic tool for Dyslexia, specifically designed for children in the second school age (the three last grades of primary school).

There were two main theoretical and research trigger points for conducting this study: (i) the wide range of symptoms observed in individuals diagnosed with "dyslexia", thus leading to general definitions of Specific Developmental Dyslexia (SDD) and (ii) the absence of integrated measurements, which are considered reliable enough for a circumstantial diagnosis of all the areas affected in cases of SDD.

In the studypresented, the term "SDD" will be used in accordance with the definition in the Diagnostic Manual of the American Psychiatric Society, where SDD is *"an alternative term referring to a particular pattern of learning difficulties characterized by problems in accurate word recognition, poor decoding and poor syllabification skills"* [4].

2. Theoretical Approaches to SDD

The theoretical approaches to understand the entity of SDD have helped define the basic cognitive functions directly associated with SDD and are consequently used to diagnose it and build relevant assessment tools.

More analytically, the theory of phonological deficit is the predominant cognitive explanation for SDD [23]; [50]; [53]; [65]; [84]. The theory argues that the inadequate representation of verbal sounds leads to difficulties related to the exact processing of spoken words [27]; [28]; Gooch et al., 2011).

Another approach, the theory of double deficit [87], relates SSD to those individuals characterized by phonological difficulties and difficulties of rapid naming (double deficit) [20]; [27]; [28]; [50]; [57]; [55]; [77]; [81]; [84]; [85].

One the most prevailing hypothesis of the underlying cognitive causes of SDD involves the effectiveness of short-term memory in reading (dis)abilities [29]; [33]; [36]. The approach was originally reported by Baddeley and Hitch (2000), who argue that the phonological circuit and the visual array are controlled by the short and episodic buffer. The theory developed describes that weaknesses in the perception or processing of speech phonological units, result in difficulties in matching oral and written discourse. It therefore concerns the disruption of the decoding capacity, since the inappropriate processing of the phonic information causes problems in the use, recovery and preservation of the phonic information in the memory. That is, it creates phonological awareness problems [8]; [51]; [62].

Based onthe model of auditory processing [23]; [78], phonological awareness depends on the auditory processing of verbal information [23]; [75]. Goswami and his colleagues (2010) report that the phonological processing hypothesis is not a sufficient explanation of the auditory difficulties posed by people with cognitive difficulties and suggest that it is more appropriate to focus on the perception of the acoustic signals that exist in speech (such as rhythm, time, and intensity).

The biological approach, more specifically the theory of motor-visual processing, states that the origin of visual difficulty can be detected in the large cell and intracellular system [23]. A general explanation broadly accepted by a large number of scholars is that the problem of eye movement is a consequence rather than a cause of SDD [23]; [68].

Visual attention, i.e. the ability of rapidly selecting summary information, relates to various aspects of the reading process and is important at all levels of processing a series of letters [15]; [23]; [26].

As concerns the theory of cerebellum [23], the existence of a motor deficit can lead to disturbed phonological representations [9]; [70].

In recent years, the published work also highlights the important role that phonological awareness plays in SSD. An important point in phonological processing, the voice concept which is the coding of phonological information [19]. Coding contributes to the comparison and learning of sounds and word structures, i.e. distinguishing homonymous words [23]; [53]. Phonological memory detects and prevents repetition of misspelled words and phonological learning helps to identify pseudo-words [20]; [27]; [28]; [32].

The relevance of short-term memory in SDD is commonly accepted by the scientific research community [2]; [36]; [51]; [53]; [52]; [62]. Nielsen et al. (2016) report the storage and processing of working memory in the following stages: (a) Phonological coding and word reproduction, (b) spelling of words or texts, (c) morphological coding (auditory and written), (d) editorial structure of a series of words and (e) self-correction by the person (spoken or written) through auditory and visual feedback [29]; [33]; [51].

It is also reported that people with SDD face difficulties in reading and writing [12]; [54]; [57], which can be attributed to multiple factors [1]; [6]; [12]. According to Altemeier et al. (2008), it appears that executive functions incorporate visual and linguistic information whenever memory is used in the learning process [61].

In addition, difficulties in reading and writing are linked to difficulties in repeating words, retrieving verbal elements from short-term memory and difficulties in using phonemes [25]; [76]. Therefore, the role of phonology, memory and rapid automatic naming is dominant in SDD.

Also, a predominant prognostic indicator for SDD is rapid automated naming [27]; [58]; [77]. As Morken and Helland (2013) report, students with SDD face a problem in spontaneous writing and rapid naming, thereby inhibiting the executive function, as well as limiting verbal freedom, which may also explain the problems in spelling.

2.1 Diagnostic Criteria of Special Developmental Dyslexia

The diagnosis of SSD in Greece is carried out in accordance with the two international handbooks for the classification of disorders, (a) the International Statistical Classification of Diseases and Related Health Problems (ICD-10) [88] and (b) the Diagnostic and Statistical Manual of Mental Disorders (DSM-V) [4]. ICD-10 for Developmental Dyslexia uses the term “Specific Reading Disorder”. The DSM-V term for SDD is “Specific Learning Disorder”, so the specialist must in any case identify the areas and individual skills affected by the disorder [4].

In the pilot study presented in this paper, the DSM-V diagnostic criteria were used to construct the “Dyslexia Test” and to extract the individual profiles of SDD pupils. According to APA (2013), the DSM-V diagnostic criteria are four: (i) difficulties in learning and using academic skills, as indicated by the presence of at least one of the following symptoms that have persisted for at least 6 months, despite the provision of interventions that target those specific difficulties: inaccurate or slow and laborious reading of words, difficulty in understanding the concept they are reading, difficulties in spelling, difficulty in writing, sequencing and computations, difficulties with mathematical logic, (ii) influenced academic skills are qualitatively and quantitatively significantly lower than expected according to the individual’s age and significantly affect academic or professional performance or daily life activities, (iii) learning difficulties begin during school-age, but are not entirely clear until the requirements for incomplete academic skills exceed the limited ability of the individual, (iv) learning difficulties are not better explained by mental disability, poor visual or auditory acuity, other mental or neurological disorders, psychosocial adversities, lack of proficiency in the language of academic teaching or inadequate teaching instruction.

2.2 Diagnostic tools of SDD: what do they test?

Tests for SDD allow the objective assessment of the student’s learning, cognitive and linguistic behaviour [1]; [42]; [73]. The tests assess areas directly linked to SDD such as phonological awareness [71]; reading [1]; [18]; [41]; [55]; [73]; [67], writing [63], and cognitive functions such as memory, phonological awareness, neuro-psychological maturity [59], confirming a great heterogeneity in symptoms [49].

In accordance to the literature, all these tools include a vast array of tasks through which the following are tested: inaccurate or difficulty in word recognition, spelling and phonological decoding as well as difficulties in reading [4]; [25]; [30] words and pseudowords [11]; [44]; difficulties in accuracy, speed and comprehension [4]; [40]; [46]; [25]; and omissions or repetitions of letters, syllables, words or sentences, simplification of symphonic clusters, losing the lines in the text and skipping punctuation [4]; [49].

Interestingly, essential difficulties that diagnostic tools of SDD deem necessary to evaluate, are those which occur in writing with regard to syntax and morphology [21]; [66]; [54]; [74]. More specifically, diagnostic tools are need to test in depth the difficulties concerning slow writing, illegible handwriting, limited vocabulary, expression of limited or often repeated ideas and incomplete content [4]; [21]; [49], as well as difficulties in metacognitive strategies [64], resulting in a poor revision of the text.

In line with the above, the international literature [13]; [16]; [39]; [42]; [86] as well as the DSM-V diagnostic criteria for SDD [4] enrich the aspect that the cognitive sub-tests emerging as dominant for the manifestation of SDD are considered to be phonological awareness, memory, reading ability, spelling and application of grammatical rules [7]; [34]; [37]; [54]; [67]; [79]; [80].

In order for a clear and safe diagnosis of SDD to be achieved, it is very important all difficulties that may coexist (such as difficulties in understanding the text and the mathematical sequence) to be identified [4]; [34]; [55]; [80]. When basic functions are disordered (regardless of underlying causes) these are prognostic factors for the development of the SDD [1]; [6]; [12]; [83]. This has been extensively studied and researched in the international

bibliography and included in the diagnostic criteria of SDD [3]; [74]; [75]; [90].

In light of the above theoretical data, the authors, in their way to contribute to the psychometric analyses of SDD, are seeking to: (i) construct a comprehensive diagnostic tool, "Dyslexia Test", including sub-teststhat potentially reveal concrete symptoms of the SDD profile, focusing on the second school age (the three last grades of primary school); (ii) assess the degree of reliability of tasks included in each sub-test, indicating their diagnostic value; (iii) determine the validity of tasks included in each sub-test and consequently stress the dominant tasks and sub-tests which lead to a reliable diagnosis of SDD.

3. Methods

The pilot testing took place in private schools located in the cities of Ioannina and Thessaloniki (Greece). The participants included children between 8-11 years (average age was 9.5 years) studying in grades C, D and E of the Greek primary school system. The selection was random and resulted in 70 students (three pupils in grade C, sixty-six pupils in grade D and one pupil in grade E).

The "Dyslexia Test" test consists of five sub-tests: "Grapho-phoneme Correspondence", "Sequence Memory", "Reading", "Writing and Spelling" and "Grammar". Each sub-test includes the following tasks (here after, variables):

[1] "Grapho-phoneme Correspondence": 1.a "Combining Phonemes"; 1.b "Acoustic and Written Distinction of Phonemes"; 1.c "Audio Visual Distinction of Syllables"; 1.d "Combining Sounds".
[2] "Sequence Memory"; 2.1.a "Sequencing Images"; 2.1.b "Memory Recalled via images repetition"; 2.1.c "Memory Recalled via words repetition"; 2.2 "Events Recalled from Memory".
[3] "Reading": 3.1 "Reading Words"; 3.2 "Reading Sentences"; 3.3 "Reading Texts".
[4] "Spelling": 4.1 "Spelling Copy Word"; 4.2 "Spelling Copy Sentences"; 4.3 "Spelling Texts"; 4.4 "Text Composition".
[5] "Grammar": 5.1 "Hyphenation" 5.2.a "Locating Articles"; 5.2.b "Gender Recognition"; 5.3 "Spelling of Words"; 5.4 "Transforming singular into plural and vice versa"; 5.5 "Use of appropriate type of verbs and nouns".

The procedure included handing the test material to the students, so that they could examine it, as well as handing them a record sheet where they were asked to write their answers to each of the tasks of each sub-test. The examiner recorded the respondent's answers in an examination sheet, as well as any comments that were deemed necessary.

The time required to complete the test differed from student to student, though students were given a time limit of 90 minutes (1 hour and 30 minutes) to complete the test.

4. Statistics

In order to determine the extent to which specific sectors (sub-tests) and the respective variables of a measurement predict SDD's profile, statistical analysis was performed. Internal coherence analysis was conducted to investigate whether the variables measure the concept for which they were constructed. The Cronbach's α index [72] was used as well as the Stepwise Linear Regression method in order to define the best model for the most predictive variables.

In addition, two forms of validity were performed: the content's validity and structural validity, while testing the difficulty factor for both tasks. All the data analysis and statistical analysis, which lead to the extraction of results, was performed using the SPSS (Statistical Package for the Social Sciences) software [24].

5. Results

The statistical analysis led to the following results:

1) Hierarchy of variables based on internal coheren credibility

For an acceptable value, Cronbach's α index should be > 0.7 [72]. According to this model, the credibility of the internal coherence of the variables chosen amounts to 0.653. It was found that the most important variables, which if separated would decrease the credibility index of all the rest, were "Reading Words", "Reading Texts", "Spelling Copy Sentences", "Spelling Texts", "Transforming singular into plural and vice versa". Less important were "Text Composition", "Hyphenation", "Memory Recalled via words repetition".

Table 1: Hierarchy of variableson the basis of the Cronbach's α index

Variables	Scale Mean (if variable separated)	Scale Variance (if variable separated)	Cronbach's α (if variable separated)
"Reading Words"	104.03	2552.75	0.56
"Reading Texts"	110.44	2897.03	0.60
"Spelling Copy Sentences"	103.41	2849.23	0.60
"Spelling Texts"	97.43	2398.04	0.62
"Transforming singular into plural and vice versa"	111.81	3268.49	0.63
"Reading Sentences"	113.15	3281.98	0.63
"Use of appropriate type of verbs and nouns"	112.09	3296.35	0.64
"Combining Phonemes"	110.34	3301.39	0.64
"Gender Recognition"	113.21	3355.30	0.64
"Spelling of Words"	113.75	3343.03	0.64
"Events Recalled from Memory"	112.24	3364.06	0.65
"Gender Recognition"	113.75	3374.82	0.65
"Acoustic and Written Distinction of Phoneme"	113.13	3387.31	0.65
"Audio Visual Distinction of Syllables"	114.21	3409.21	0.65

"Locating Articles"	111.87	3404.15	0.65
"Memory Recalled via images repetition"	113.82	3430.15	0.65
"Combining Sounds"	102.49	3370.25	0.65
"Sequencing Images"	113.54	3441.83	0.65
"Memory Recalled via words repetition"	110.82	3491.55	0.66
"Hyphenation"	99.31	2696.40	0.68
"Text Composition"	99.88	3138.34	0.70

[2] The difficulty index per task

A significant research question tackled in this study was whether the "Dyslexia Test" variables were appropriate to draw safe conclusions about the potential difficulties that the student encounters. The difficulty index results are presented in Table 2. The difficulty index of the variablesranges between 76% - for the most difficult - to 7% for the least difficult (Table 2). "Memory Recalled via words repetition" was shown to have the highest difficulty index, while "Audiovisual distinction of syllables" appeared to be less difficult. It seems that the greatest difficulty index was associated with the tasks of "Memory Recalled via words repetition", "Combining Sounds", and "Text Composition".

Table 2: Average of difficulty index per variable

Sub-test	Exercise	Average of difficulty index (%)
1. "Grapho-phoneme"	1.a "Audio Visual Distinction of Syllables"	28
	1.b "Acoustic and Written Distinction of Phonemes"	10
	1.c "Combining Phonemes"	7
	1.d "Combining Sounds"	43
2. "Sequence Memory"	2.1.a "Sequencing Images"	23
	2.2 "Events Recalled from memory"	27
	2.1.b "Memory Recalled via images repetition"	30
	2.1.c "Memory Recalled via words repetition"	76
3. "Reading"	3.3 "Reading Texts"	09
	3.1 "Reading Words"	18
	3.2 "Reading Sentences"	27
4. "Spelling"	4.2 "Spelling Copy Sentences"	19
	4.1 "Spelling Copy Word"	19
	4.3 "Spelling Texts"	29
	4.4 "Text composition"	37
5. "Grammar"	5.2.b "Gender Recognition"	8
	5.4 "Transforming singular into plural and vice versa"	8
	5.2.a "Locating Articles"	12
	5.3 "Spelling of Words"	25
	5.5 "Use of appropriate type of verbs and nouns"	26
	5.1 "Hyphenation"	36

As shown in Table 2, in the "Grapho-phoneme Correspondence" sub-test, the main problem encountered by the students was the "Combining Sounds" and to a lesser extent the "Audio Visual Distinction of Syllables". Similarly, in the "Sequence Memory" sub-test, "Memory Recalled via words repetition" had a higher difficulty index compared to "Sequencing Images". In the "Reading" sub-test, the highest difficulty index was recorded in "Reading Sentences" and to a lesser extent in "Reading Texts".

In the "Spelling" sub-test, the most difficulties were recorded in the tasks "Text Composition" and less so in "Spelling Copy Sentences".

Finally, in the "Grammar" sub-test the highest index was found for "Transforming singular into plural and vice versa", with a lower difficulty index found for "Locating Articles". [3] Stepwise Linear Regression was used to emerge the dominant tasksrepresenting the sub-tests that lead to the diagnosis of SDD.

Through the analysis, five models with high significance were established, including the most predictive tasks of each sub-test for the formation of dyslexic profiles (Table 3).

Table 3: Model summary for the Stepwise Linear Regression

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
3.2	.643	.414	.405	.378	.414	46.585	1	66	.000
3.2, 4.3	.731	.535	.521	.339	.121	16.958	1	65	.000
3.2, 4.3, 2.1.c	.784	.615	.597	.311	.080	13.237	1	64	.001
3.2, 4.3, 2.1.c, 5.3	.816	.666	.645	.292	.051	9.689	1	63	.003
3.2, 4.3, 2.1.c, 5.3, 5.5	.830	.690	.664	.284	.023	4.679	1	62	.034
Note: 3.2, "Reading Sentences"; 4.3, "Spelling Texts"; 2.1.c, "Memory Recalled via words repetition"; 5.3, "Spelling of Words"; 5.5, "Use of appropriate type of verbs and nouns".									

6. Discussion

The results that emerged from the statistical analysis showed that the sub-tests that were most considered as significant indicators for measuring and formulating an SDD profile were "Reading", "Spelling", "Sequence Memory", "Grammar". Similarly, the significant tasks that emerged from the statistical analysis were "Sentence Reading", "Spelling Texts", "Memory Recalled via Repetition", "Spelling of Words", "Use of appropriate type of verbs and nouns".

Analysing these findings, in terms of reading skills, the main difficulties are observed at the sentence level, while in terms of s spelling skills, difficulties are observed at both the word and the text level.

Moreover, in understanding the above difficulties it should be taken into consideration that the test is administered to higher age groups (students in the upper grades of the primary school). Thus,it could be thought that strongly inadequate metacognitive reading skills are indicated in students with SDD in terms of organisation skills (syntax, grammar) and understanding the meaning of a text, in line with other scientific findings [14]; [31]; [43].

Similarly, "Sequence Memory" was shown to be a reliable predictive variable of SDD profile; a finding that is consistent with other publications [8]; [18]; [29]; [33]; [51]; [60]; [76].

As already highlighted in the literature, basic processes in learning to read are coding, storage and retrieval of verbal and written correlations [2]; [36]. The vocabulary process is based on the visual recognition of a series of letters that form a particular word [29]; [89]. Consequently, the name of this word and its relative significance must be retrieved from long-term memory [5]; [19]; [23]; [38]; [49]; [69].

In the present study, such sequence memory evaluation tasks were included in the "Sequence Memory" sub-test. Recent findings from studies confirm the direct relationship between short-term and working memory with SDD [7]; [36]; [37]; [51]; [62]. Accordingly, the "Sequence Memory "sub-test points out with high reliability the difficulties in recalling the sequence of images, categories (colours, shapes, numbers), words (through the process of repetition), and events.

The results indicatethat students with difficulties in "Sequence Memory", encountered difficulties in both "Grapho-phoneme correspondence" and "Spelling" sub-tests.

An explanation is given by Morken and Helland (2013), who support that phonological awareness is not only a validated prognostic marker for the ability to read but also for spelling [17]; [74]; [82]; [86].

Besides, phonological awareness is widely accepted by researchers as a core factor of SDD [7]; [17]; [19]; [28]; [32]; [53]; [54]; [74]; [90].

In line with this assumption, as shown in the "Grapho-phoneme Correspondence" sub-test, the main problem encountered by the students with high reliability was in "Combining Sounds", "Combining Phonemes", "Acoustic and Written Distinction of Phoneme" and to a lesser extent in the "Audio Visual Distinction of Syllables" variables [37]; [86].

"Spelling" and "Grammar" sub-tests were also found to be significantly predictive for diagnosis of SDD profile, in line with current literature, as they concern both morphology and the writing process. More specifically, morphology is regarded as an important factor in the development of reading and writing skills [7]; [47] asmorphological awareness is related to the awareness of the smaller parts of a word, which, however, have some semantic meaning [22]; [47]. In one word there is the base (the fixed part of it, which cannot be changed because the word will no longer exist) and the variable part of the word that can change its grammatical (gradient, gender) and semantic status, through addition or replacement [20]; [57]; [60]; [75].

In addition, writing refers to the conversion of spoken language into written symbols. The relationship between difficulty in writing and SDD is widely recognized [3]; [10]; [54]. Types of writing are spontaneous text, dictation and copying [52]. Writing is a complex task that involves the development and co-ordination of a set of skills (motor-visual coordination, spelling, legible letters, word-separation, grammatical rules) [12]; [82]. Kim et al. (2014) concluded that automated word writing with correct spelling plays an important role in enhancing vocabulary that children should match with their age.

It is worth noting that the sub-tests of "Spelling" and "Grammar" did not target testing general writing difficulties, that a student or a poor reader might present. These sub-tests focused primarily on the writing difficulties which occur in SDD and coexist with reading and consequent problems in syntax and comprehension of the text. Similarly, it is found that the appropriate application of grammatical rules does not concern only writing skills, but also speaking [7]; [54]; [57]; [45]; [52]; [35]; [82].

The construction of the proposed "Dyslexia Test" was based on the basis that the differential diagnosis of a student with SDD, as opposed to one that is characterized as a weak reader, plays a catalytic role in the approach of the problem diagnosed. Timely and valid diagnosis, using appropriate and standardized diagnostics tools, leads to appropriate individualized therapeutic intervention.

6.1 Limitations

Overall, the pilot study demonstrated the successful application of the test and provided valuable feedback for improvement. It is considered important to reduce the administration time of the "Dyslexia Test", so that the student does not succumb to errors related to fatigue. Finally, the sample used (test participants) is considered suitable for a pilot study, but as the main objective of the "Dyslexia Test" is to be standardized using a larger student

population, it is estimated that the sample should be raised to 2000 students studying in primary schools across Greece.

7. Conclusions

The proposed "Dyslexia Test" is designed for an integrated diagnosis of SDD. Itis targeted to formulate a diagnostic profile that is representative of SDD characteristics only and not those of general learning difficulties.

In this regard, the areas that emerged as those most appropriate for assessing and determining the SDD profile, are those of sequence memory, reading and spelling skills, as well as grammar acquisition. In reading, the core difficulties are assumed to be at the level of sentence, while spelling is indicated as that area which is most affected and presents the serious difficulties, even at the word level.

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