



A Self-report Oriented Toward Visuoperceptive and Visuomotor Alterations for the Early Identification of Dyslexic Children

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Authors' contributions

This work was carried out in collaboration between both authors. Author CR performed the bibliographic research, tested the patients and wrote the first draft of the manuscript. Author CA designed the study, performed the statistical analysis and revised the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Background: Early diagnosis is the main requisite for rehabilitating children suspected to suffer from dyslexia, and self-reports may be as reliable as ordinary screenings, but far less expensive. Research shows that the visual function can be involved in the pathogenesis of dyslexia so that self-reports should inquire about visual signs as well. A questionnaire made of 21 items that provide scores based on the visual signs commonly reported by dyslexics and on the most relevant comorbidities according to the literature has been devised. The aim of this exploratory study is to evaluate its potential for the early identification of dyslexic children.

Methods: The AAP-DD is a set of 21 items subdivided into 4 sections that inquire about visual signs (section S), fatty acid deficiency, inheritance of dyslexia, and related conditions in children and parents. Each item is assigned a specific visuomotor and visuosensory weight in the form of a coefficient. The parents of twenty-three dyslexic children (9.34±0.80 years) and twenty-four normal readers filled the questionnaire. To assess the correspondence between the outcome of the questionnaire and the actual visual function of each participant, spatial relationship perception and ocular movements have been tested psychophysically.

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Results: The score of the dyslexic sample was almost double (i.e. worse) compared to the control group ($P < .0001$). Sensitivity and specificity were, respectively, 87% and 62%. Section S was the most informative, accounting for up to 41% of the variance of the reading rate. Correlation between the DEM and the AAP-DD scores suggests the questionnaire reflects the actual visuomotor condition of the subject.

Conclusion: The AAP-DD seems promising to screen children at risk for dyslexia, and is, therefore, worth to be further investigated in a larger population. The obtained results support the role of the visual function in the pathogenesis of this condition.

Keywords: Dyslexia; self-report; DEM; vision; risk factors.

ABBREVIATIONS

AAP-DD : Developmental Dyslexia Analytic Anamnestic Protocol;

VM : Visuo Motor coefficient;

VS : Visuo Sensory coefficient;

HT : Horizontal Threshold

1. INTRODUCTION

The collection of an accurate medical history is the first step for managing a clinical condition. Information reported by the patient is pivotal for orienting towards the diagnosis or the prognosis. Yet, how much the familial and medical history is informative for this purpose depends on the expertise as well as on the analytical capacity of the physician. The transformation of the merely descriptive familial and medical history into a pattern of quantifiable data provides an objective starting point for the subsequent examinations, less influenced by subjective criteria and suitable for analytical computations.

In the last few years, indeed, a strand of research has addressed this issue, managing to turn the pieces of information that make up the familial and medical history into a score, so that the higher (or the lower) the score, the higher the likelihood of a pathological event or the risk it can occur in the future. Examples are the Framingham Risk Score for the risk of coronary heart disease [1], a diagnostic score aimed at predicting diabetes [2], the DASH score to predict the recurrence of venous thromboembolism [3], and the score of Menekse and colleagues to predict mortality in patients with perforated peptic ulcer [4]. In the ophthalmological field algorithms like the STAR (Scoring Tool for Assessing Risk) scoring systems [5] and, more recently, the East London Glaucoma Prediction Score (ELGPS) have been introduced to quantify the risk of developing glaucoma [6].

In line with these assumptions, predicting dyslexia (a specific reading disability that occurs

despite adequate instruction and education, normal intellectual abilities and socio-cultural background, and is not caused by reduced visual acuity or psychiatric pathologies) before it can be formally diagnosed is essential: early diagnosis, in fact, is important to maximize the rehabilitative outcome [7]. And yet, this goal is difficult to achieve as the diagnosis is based on the measure of the reading performance (unattainable before the third grade of primary school), and the rate of development of the lexical function differs significantly among children. In addition, large scale screenings are time-consuming and, as for Italy, financially difficult to afford. Self-reports could overcome these problems, provided they are reliable. A bulk of research reports a correlation between self-report and phonological testing, and questionnaires inquiring about the lexical performance and attitude to reading revealed to be promising [8-16]. These studies are devoted to adult dyslexics or to parents of dyslexic children and provide a measure of literacy in adulthood. On the contrary, the way to predict dyslexia in children is an open question: unlike the questionnaires devised for adults, in preschool children inquiring about the lexical performance and attitude to reading is not possible. The items cannot but investigate the risk factors.

Polyunsaturated fatty acids (PUFAs) deficiency [17,18], prematurity, allergic or autoimmune diseases, neonatal jaundice, risk of abortion, smoking during pregnancy and other clinical or behavioral conditions are shown to be related to dyslexia [19-23]. Collecting information about these risk factors with a self-report may be the key to detect children at risk for dyslexia at preschool age. In addition, a bulk of research suggests that subtle visuoperceptive impairments may selectively affect dyslexics (See [24] for a comprehensive review): there is, therefore, reason to suppose that the clinical signs suggesting the presence of subtle

visuoperceptual dysfunctions or visuomotor weakness described in dyslexic children are useful indicators of their predisposition to develop this condition at a later stage of development: thereby, including these aspects in a self-report could improve its predictive power.

In a previous study, the Analytic Anamnestic Protocol (AAP), has been developed to ascertain if alterations of the visuomotor and sensory function may be predictive of a neuro-ophthalmological impairment in selected pathological groups (children with cerebral lesions and with genetic diseases [25]). The AAP is a multiple-choice questionnaire aimed at collecting and scoring visual signs and symptoms reported by the patients or by their closest family members. Each answer is assigned a predetermined visuomotor (VM) and a sensory (VS) coefficient. At the end of the questionnaire, the sum of the VM and VS scores are computed. Sensitivity and specificity were 76.3% and 92.5%, respectively. To make the AAP specific for dyslexia, 5 items inquiring about the most representative visual signs reported in dyslexic children have been added and the non-specific items have been removed or replaced with questions investigating the risk factors of dyslexia according to the current literature.

This first, exploratory study aims to probe the effectiveness of this modified version of the AAP (AAP-DD) in predicting children at risk for developmental dyslexia. To do so, a sample of dyslexic children and a group of normal readers has been administered the protocol, and ROC analysis has been conducted on the results of the questionnaire. In addition, a correlation analysis between AAP-DD score and reading rate, and between AAP-DD score and two visual tests has been performed to assess the correspondence between the actual reading and visual function and that predicted by the protocol in each participant.

2. MATERIALS AND METHODS

2.1 The AAP-DD Self-report

The AAP-DD self-report is a set of 21 items that investigate the presence of the signs and symptoms most commonly reported by dyslexic children as well as the most important comorbidities according to the literature (Table 1). The items investigate visual perceptual signs, fatty acid deficiency, inheritance of dyslexia, systemic clinical conditions correlated to this

form of reading disability as well as attention deficit hyperactivity disorder (ADHD). The parent has to mark on a scale the grade that best fits his/her condition or the condition of his/her son. Each item is assigned a specific visuomotor (VM) and visuosensory (VS) weight in the form of a coefficient. The coefficients depend on the clinical variable the item probes (see Table 1, first item for an example).

The total VM and VS score is computed as the sum of the VM and VS score collected for each of the 21 items. These indices quantify the expected loss of visuomotor and sensory function compared to the ideal condition (zero VM and zero VS scores) so that the higher is VM and VS, the more severe is the expected loss of efficiency in the visuomotor or sensory domain. The maximum VM score and the maximum VS score in the hypothetical worst condition are roughly the same.

2.2 Testing the Visuoperceptive and Visuomotor Function

Among the visuoperceptive alterations reported in dyslexics, the one that probably best accounts for their reading difficulty is increased paracentral crowding [34-37]: in fact, excessive lateral inhibition between letters hampers their recognition, thereby reading. In a previous study [38] we postulated this effect depends on increased horizontal anisotropy of the visual space and, with a test devised on purpose (eidomorphometryTM) we found evidence that this alteration affects a proportion of dyslexic children [38,39]. The test has been described in detail in a previous study [39]. In substance, it quantifies the perceived difference in the extent of a bidimensional shape along the x/y cardinal coordinates. The procedure makes use of a staircase psychophysical algorithm to estimate the discrimination threshold between circles and horizontal ellipses oriented along the x/y coordinates. The threshold is expressed as Interaxis Ratio (IR%) that is the percent difference between the focal and the perpendicular axis. The recognition threshold of the horizontal ellipses (Horizontal Threshold, HT) is assumed to reflect the anisotropic contraction of the visual space, making adjoining letters perceptually closer than they are. According to Bouma [40], below a given interletter distance crowding takes place, so that the correct identification of the characters, thereby reading, is degraded.

Table 1. The 21 items of the AAP-DD. The questions are referred to: visual-perceptive aspect (S), fatty acid deficiency (FA), inheritance of dyslexia (INH), systemic clinical conditions putatively correlated to dyslexia in the child (CHI) and parents (PAR), and attention deficit hyperactivity disorder (ADHD). Many of the items involve a scalar response (see item S1 for an example)

Question code	Question	References that legitimate the question
S1	1-When reading, does your son mix up syllables? (never → almost constantly)	[26] Stein & Walsh, 1997
	<p>0 1 2 3 4 5 6</p> <p>-----</p> <p>NEVER ALMOST CONSTANTLY</p> <p>0 never 4 often</p> <p>1 rarely 5 very often</p> <p>2 sometimes 6 almost constantly</p> <p>3 quite often</p> <p>M=6 *score</p> <p>S= 10*score</p>	
S2	2- When reading, does your son see letters jumping or moving? (never → almost constantly)	[27] Raghuram et al, 2019
S3	3-When reading does your son ever reverse the syllables? (never → almost constantly)	[26] Stein & Walsh, 1997
S4	4-When reading does your son ever complain of intermittent blurring? (never → almost constantly)	[27] Raghuram et al, 2019
S5	5-When reading does your son ever lose his/her place? (never → almost constantly)	
FA1	6-Has your son dandruff problems? (never → almost constantly)	[17] Baker, 1985; [18] Taylor et al, 2000
FA2	7-Is your son's skin dry? (never → almost constantly)	
FA3	8-Is your son thirsty? (never → very often)	
FA4	9-Does your son frequently feel the urge to urinate? (never → often)	
INH	10-Is any parents or first-grade relatives dyslexic? (no → both parents)	[28] Pennington & Gilger, 1999; [29] Stein & Talcott, 1999
ADHD	11-Has your son an attention deficit hyperactivity disorder (ADHD)? (no→ yes, assuming pharmacological therapy)	[30] Willcutt et al, 2000
CHI1	12-Does your son suffer from allergies (asthma, eczema, hay fever)? (no → yes, requiring steroid assumption)	[19] Hugdahl et al, 1990
CHI2	13-Is your son born preterm? (no → < 28 th week and/ or birth weight < 1 Kg)	[31] Mascheretti et al, 2018
CHI3	14-Does your son suffer from bouts of otitis? (never → often)	[32] Golz et al, 2015
CHI4	15-Has your son hearing problems? (no → yes)	
CHI5	16-Did your son suffer from hyperbilirubinemia at birth (neonatal jaundice)? (no/yes)	[22] Hokkanen et al, 2014
PAR1	17-Does a parent suffer from autoimmune/rheumatologic diseases? (no → yes, with severe symptoms)	[19] Hugdahl et al, 1990
PAR2	18-Does a parent or a relative suffer from epilepsy or Parkinson's disease? (no/yes)	[23] Liu et al, 2016
PAR3	19-Did the mother contract any infectious diseases during pregnancy (rash illness)? (no/yes)	
PAR4	20-Did the mother smoke during pregnancy? (no/yes)	[20] Cho et al, 2013
PAR5	21-Has your pregnancy been at risk of abortion? (no → high risk)	[21] Mascheretti et al, 2015; [33] Gilger et al, 1992

The choice of this test to assess visual perception is dictated not only by the fact that it is an indirect indicator of crowding but also because it is user-friendly and is suitable even to preschool children since it does not involve alphanumeric symbols. In turn, the DEM has been adopted to evaluate the visuomotor function. The DEM is a psychometric test that quantifies ocular-movement skills by performing a task of localization and naming of single-digit numbers matrices, in a simulated reading-like condition [41].

2.3 Reading Rate Assessment

The reading rate was measured with the MT reading battery of Cornoldi and Colpo [42], a widely used reading test in Italy. The MT reading battery quantifies the reading rate of brief passages of words and non-words in syl/sec (number of syllables read / time) and a Z score is provided. The tool is standardized for the Italian population for primary school classes. Reading rate was used as a marker of reading disability in patients with a diagnosis (DD sample). In addition, the reading rate for non-words was assessed in each patient with presentations of strings of words nonsense. More in detail, 22 presentations were displayed in a randomized order on a high-resolution LCD screen. Each presentation was made of 5 non-words made of, 2, 2, 2, 3, and 3 syllables (font: Free Monospace). Mean character size was 0.4 deg at a viewing distance of 70 cm. The luminance of the background was 85 cd/m², the luminance of the letters was 0.3 cd/m². The subject, who was seated in a quiet and well-illuminated room, was required, without being urged to the best performance, to read aloud each presentation in binocular conditions. Each presentation remained visible on the screen the time necessary to be read. Reading rate in both tests is expressed as syllables per second.

2.4 Sample

Twenty-three dyslexic children (10 males, 13 females, mean age: 9.34 ±0.80 years) with normal ocular and general health conditions who were attending the third, fourth, and fifth grade of primary school were recruited from the outpatient clinic of the Neuro-Ophthalmology service. The formal diagnosis of developmental dyslexia was provided by the reference neuropsychiatric service according to the criteria outlined by Stanley and Hall [43] in 1973 (reading delay of at least 2.5 years, average to above-average

intellectual ability, performance equal to normal readers in other academic subjects, normal IQ as measured by the WISC-R scale, and absence of gross behavioral problems and auditory impairment). Exclusion criteria were best-corrected visual acuity < 60/60, refractive defects >± 4 diopters, eso/exotropia, and general or ophthalmological diseases.

As a control group, twenty-four normal readers of the same average age (14 males, 10 females, mean age: 9.75 ±0.84 years, *P* >.05) with normal ocular and general health conditions were selected from the outpatient clinic of the Neuro-Ophthalmology service. Exclusion criteria in the control group were neuropsychiatric conditions, IQ<90 (as measured by WISC-R scale), auditory impairment, best-corrected visual acuity < 60/60, eso/exotropia, and general or ophthalmological diseases.

The children were administered the tests in random order, then the self-report was handed to the parents (CR). Data were analyzed after all the questionnaires had been given back to the experimenter by a second researcher (CA) according to a masking procedure.

The research, approved by the School of Medicine of the University of Turin as the topic of a bachelor dissertation presented on October, 18th, 2019, was performed in accordance with the tenets of the declaration of Helsinki.

3. RESULTS

3.1 Questionnaire

Reading rate in the control and dyslexic sample was, respectively: words: 3.67 (±0.82) and 0.96 (±0.29) syl/sec (t-test, Welch corrected, *t* =4.79, *P* <.0001); non-words: 1.50 (±0.49) and 0.93 (±0.31) syl/sec (Mann-Whitney, *U* =552, *P* <.0001).

The distribution of the scores referred to the motor (VM) and sensory (VS) domain in the two samples is depicted in Fig. 1.

As shown in Table 2 and Fig. 2, VM and VS scores were almost double in dyslexics compared to controls (one-way ANOVA: *P* <.0001, VM in dyslexics vs. VM in controls: Tukey-Kramer: *q*(3.71) =4.82, *P* <.01; VS in dyslexics vs. VS in controls: Tukey-Kramer: *q*(3.71) =5.24, *P* <.01. The same applies to the

cumulative scores ($q[4.09] = 7.16, P < .001$). In turn, within each of the two samples the scores referred to the sensory and the motor domain were not different (Tukey Kramer: controls: $q(3.71) = 0.36, P > .05$; dyslexics: $q(3.71) = 0.77, P > .05$).

Receiving Operator Characteristics have been computed for the cumulative scores and,

separately, for the VM- and VS- scores (Table 3).

Comparison of the cumulative, VM, and VS AROC showed no significant differences (cumulative vs VM-score: $z = 0.15, P = .87$; cumulative vs VS-score: $z = 0.25, P = .79$; VS-scores vs. VM-scores: $z = 0.26, P = .79$).

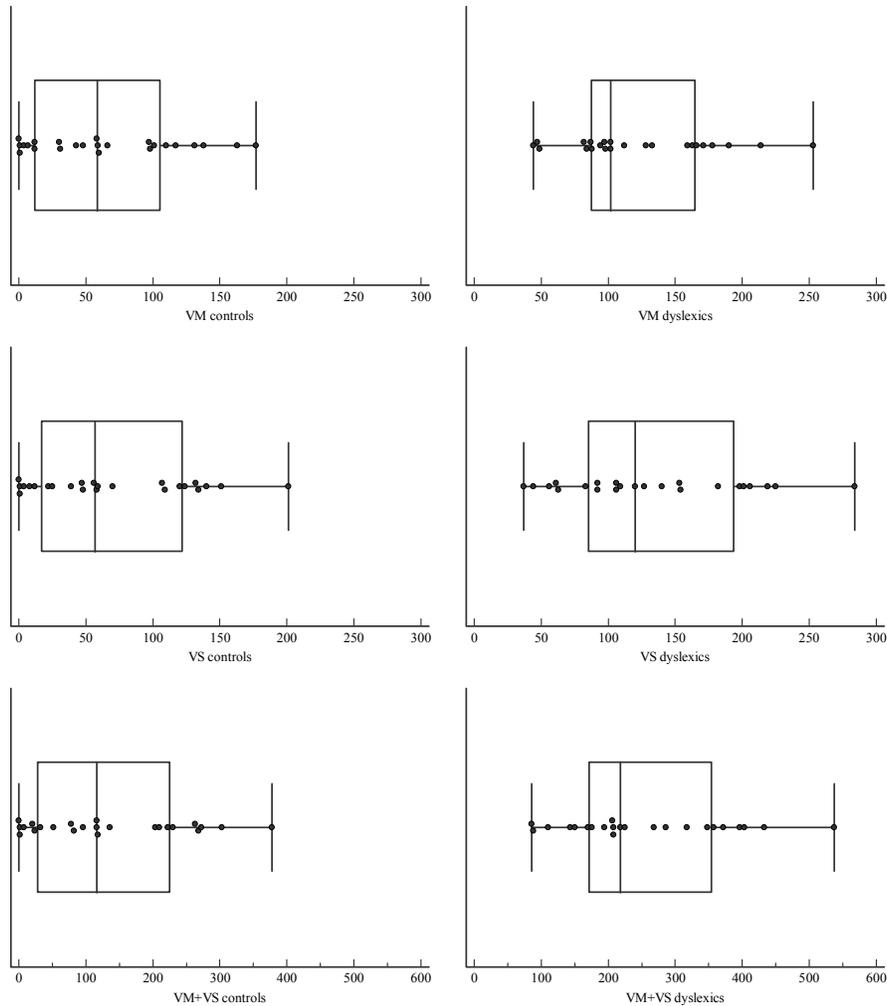


Fig. 1. Distribution of the cumulative scores (VM+VS) in the dyslexic (left) and control sample (right). Upper panels: cumulative scores; middle panels: VM scores; lower panels: VS scores

Table 2. Average scores in the two samples. In brackets is the standard deviation (SD)

	Cumulative (VM+VS) score	VM score	VS score
Dyslexic Sample	256.4 (± 120.0)	123.52 (± 54.8)	132.95 (± 66.5)
Normal Sample	134.6 (± 111.9)	65.16 (± 54.5)	69.5 (± 58.0)

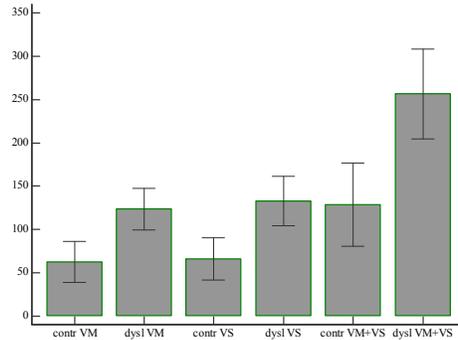


Fig. 2. AAP-DD scores of the control (contr) and dyslexic (dysl) samples. Bars refer to SD

Table 3. ROC parameters referred to the cumulative M+S score, and the VM and VS scores

	AROC	CI	Youden index	Sensitivity (%)	Specificity (%)	Accuracy (%)
Cumulative M+S	0.76	0.61-0.87	0.49	0.87	0.62	0.74
VM-scores only	0.76	0.61-0.87	0.49	0.87	0.62	0.74
VS-scores only	0.75	0.60-0.87	0.45	0.87	0.58	0.72

The ROC curve referred to the cumulative VM+VS score is shown in the left panel of Fig. 3. Setting the cutoff >136, sensitivity and specificity of the cumulative score was 0.87 and 0.62, respectively; accuracy and the Youden index were 0.74 and 0.49, respectively.

In attempt to clarify the contribution of each section of the questionnaire, ROC curves and the correspondent parameters have been computed separately. Results are summarized in Table 4.

As shown, the highest contribution is provided by section S, while the remaining items are far less informative. Noteworthy, the AUC of section S is wider than the cumulative AUC computed on all the sections of the questionnaire, suggesting,

unexpectedly, that these have a confounding effect on the predictability of the positive and negative cases (compare panel a and b of Fig. 3).

3.2 Psychophysics

When the whole sample (normal readers plus dyslexics) is analyzed, regression analysis between the reading rate at words /non-words and the AAP-DD scores returned a determination coefficients of 0.30 and 0.21, respectively ($P < .0001$ in both cases). If each section of the questionnaire is considered separately, the regression analysis is significant only for the S section where the determination coefficient is even higher, as shown in table 5 and Fig. 4.

Table 4. ROC parameters referred to the cumulative M+S score in each section of the questionnaire

	AUC	CI	Youden index	Sensitivity	Specificity	Accuracy
Cumulative VM+VS sect S	0.85	0.71-0.93	0.62	0.96	0.67	0.81
Cumulative VM+VS sect. FA	0.51	0.36-0.65	0.11	0.82	0.29	0.55
Cumulative VM+VS sect. CHI	0.51	0.36-0.65	0.11	0.87	0.25	0.55
Cumulative VM+VS sect. PAR	0.55	0.40-0.70	0.12	0.95	0.16	0.55
Cumulative VM+VS sect. INH	0.55	0.40-0.70	0.17	0.21	0.95	0.59

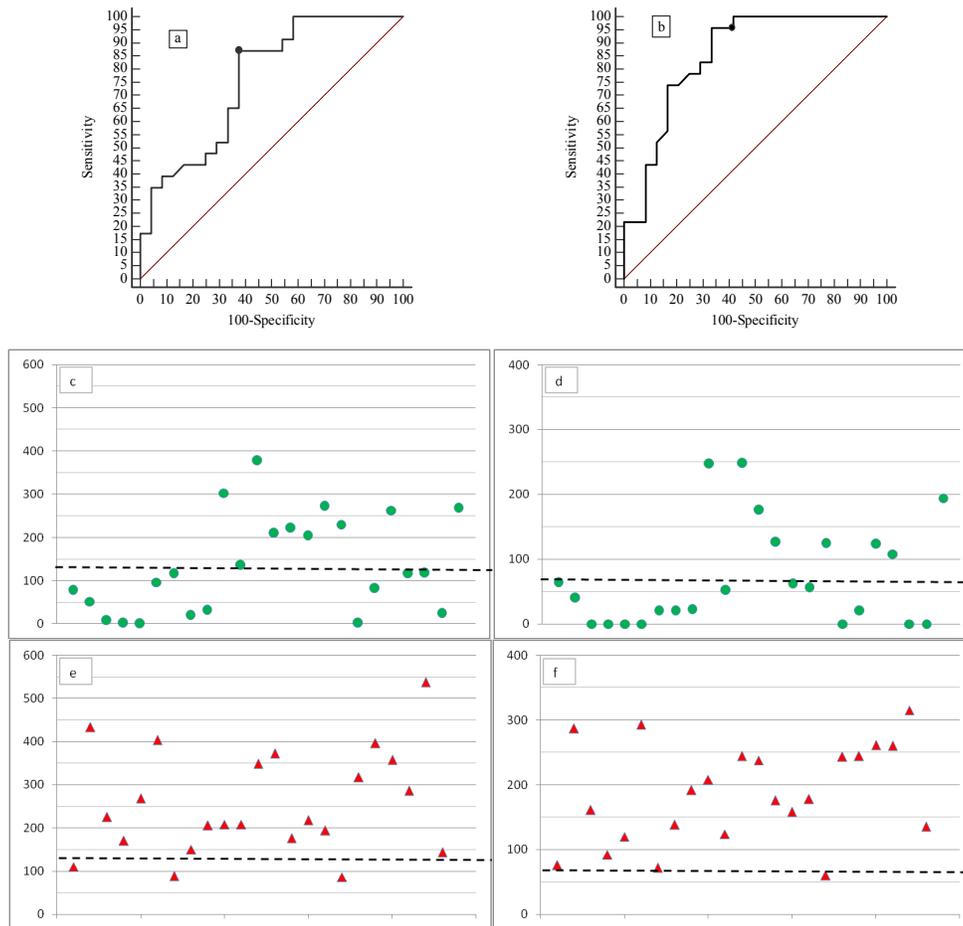


Fig. 3. Upper panels: ROC curve referred to the cumulative scores (i.e. VM+VS) of the whole questionnaire (a) and only of the section S (b). The point on the curves corresponds to the Youden index; middle and lower panels: cumulative scores of each participant obtained from the whole questionnaire (left) and only from the section S (right); c, d: normal subjects, e, f: dyslexic subjects. The dashed line corresponds to the optimal cutoff according to the Youden index

Table 5. Linear regression analysis between reading indexes and the cumulative and partial AAP-DD scores

Reading indexes	Total AAP-DD score	Section S	Section FA	Section CHI	Section PAR	Section INH
Reading rate words	0.30 (<i>P</i> = .0001)	0.41 (<i>P</i> < .0001)	0.02 (<i>P</i> = .31)	0.02 (<i>P</i> = .32)	0.004 (<i>P</i> = .64)	0.06 (<i>P</i> = .09)
Reading rate non-words	0.21 (<i>P</i> = .0009)	0.28 (<i>P</i> < .001)	0.01 (<i>P</i> = .40)	0.06 (<i>P</i> = .08)	0.008 (<i>P</i> = .53)	0.05 (<i>P</i> = .12)

In agreement with a previous study [38], the horizontal threshold was higher in the dyslexic group compared to the control sample (9.37±3.24 IR% in dyslexics vs 7.04 ±3.81 IR% in controls, *t* =2.22, *P* =.03). The horizontal threshold correlated with the reading rate (words: *r* =-0.33,

P =.02; non-words: *r* =-0.35, *P* =.01), but not with the AAP-DD scores (*r*²=0.007, *P* =.57).

Likewise, DEM horizontal time was higher in dyslexics compared to controls (73.75 ±16.20 sec vs 59.23 ±12.27 sec, *t* =3.47, *P* =.0012).

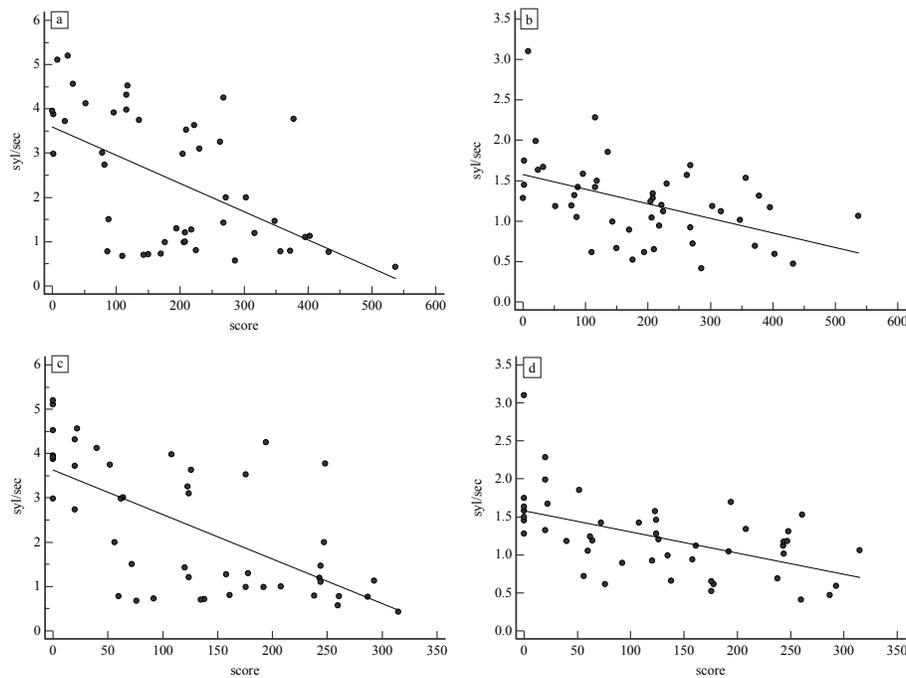


Fig. 4. Correlation between reading indexes and scores; upper panels: total AAP-DD score vs. reading rate of words (a) and non-words (b); lower panels: section S of the AAP-DD score vs. reading rate of words (c) and non-words (d)

DEM horizontal time correlated not only with the reading rate (words: $r = -0.50$, $P = .0003$; non-words: $r = -0.52$, $P = .0002$) but also with the AAP-DD scores ($r^2 = 0.18$, $P = .002$). Separate regression analysis of each section reveals that, once again, only section S is responsible for this correlation ($r^2 = 0.23$, $P = .0005$).

The contribution of these psychophysical parameters to the AAP-DD in predicting reading fluency has been determined via multiple regression analysis, with the reading rate as the dependent variable, and DEM horizontal time, horizontal threshold and the total AAP-DD score as independent variables. The regression model accounts for up to 43% of the variance ($R^2 = 0.43$, $P = .0001$). If the total score is replaced by the S section score, the multiple regression coefficient rises up to 0.50 ($P = .0001$).

4. DISCUSSION

Early diagnosis of dyslexia is a fundamental step for the effective habilitation of disabled readers. Yet, this goal is difficult to achieve: on the one hand, the diagnosis of dyslexia is based on the measure of the reading performance, that is unattainable before the third grade, on the other

hand large-scale screenings are time-consuming and financially difficult to afford. Self-reports focused on the signs and symptoms of the child as well as on his/her risk factors could overcome these problems and orienting to the diagnosis as early as before the age at which the problem can be investigated (third grade). In the last few years, indeed, a strand of research focused on the issue of diagnosis of dyslexia with the use of self-reports. Yet, as far as we know, these studies were devoted to adult subjects or parents of dyslexic children and aimed at the measure of literacy in adulthood, confirming the reliability of the self-reports for the assessment of dyslexia in the adult population [8-16]. On the contrary, the way to predict dyslexia in children remains an open question. In this respect, inquiring not only about the familial history and risk factors but also about visual signs and symptoms can improve the predictive power of the questionnaire as there is consistent evidence that visual perception is involved in the reading disability. The AAP-DD questionnaire is a self-report devised to orient toward the diagnosis of dyslexia and reading disability as early as at preschool age. It considers not only the risk factors in the familial and medical history but also the visual signs and symptoms commonly reported by this

category of subjects, according to the current literature.

In effect, visuosensory and visuomotor scores of dyslexics were almost double compared to controls, showing acceptable sensitivity (87%). In addition, section S alone shows higher sensitivity and accuracy, revealing that these selected items about visual signs and symptoms could be the most informative for screening purpose.

Indeed, an appropriate selection of specific items from a self-report had previously been reported to be the optimal solution to maximize the area under the ROC (AROC). Tamboer and associates showed that the item scores selected from the questionnaires were even more reliable compared to the total sum scores, allowing identifying as dyslexic or non-dyslexic up to 89% of students. The authors concluded that collecting items selected among those more representative of the typical difficulties of dyslexics is the most effective way for their diagnosis in adult age [14]. Considering 16 items out of the 82 questions making up their questionnaire, Tamboer and Vorst obtained a sensitivity of 92% and a specificity of 96% in their sample of adult students [15]. Despite a satisfactory sensitivity (96% of the dyslexic subjects were correctly identified by the section S of the questionnaire), the percentage of normal reader misclassified by our protocol as dyslexic was consistent. Low specificity, indeed, seems to be the main shortcoming of the AAP-DD. In turn, the probability that subjects with a negative test are dyslexics is very low, as shown by the negative predictive value (99.24% and 99.78% computed on the whole questionnaire and on the section S, respectively). It should be considered that the non-optimal identification of dyslexics and non-dyslexics is common to other tests of screening: Harrison and Nichols [44] reported a sensitivity of 74% and a specificity of 84% for the Dyslexia Adult Screening Test (DAST) in labeling subjects as "highly at risk", and a sensitivity of 85% and a specificity of 74% in categorizing subjects as "mildly at risk" of dyslexia. In the self-report devised by Snowling and associates [12] to assess dyslexia in adults sensitivity was consistently lower compared to specificity (47.44-62.5% vs. 95.85-95.04%).

It is remarkable the significant correlation between the lexical performance and the AAP-DD scores, with section S of the questionnaire that accounted for up to 41% of the variance of the reading rate. This is confirmatory of the

predictive efficacy of the self-report with respect to the reading performance. The correlation between the weight of the score provided by the section S and the horizontal time at DEM suggests that the visual discomfort and the visuoperceptive alterations reported or observed during reading and scored by the questionnaire are consistent with a subtle impairment of the visual function. Including this test to the diagnostic protocol may improve its effectiveness.

Our preliminary results suggest, with due caution, that specific visuoperceptive signs have a high predictive value for dyslexia in preschool children. Raghuram and colleagues examined the occurrence of visual symptoms in dyslexic children (aged 7-11 years) using 9 items of the CISS (Convergence Insufficiency Symptom Survey) and studied the correlation between the CISS score and the visuomotor function administering the DEM [27]. As in our study, the authors found that the average score was higher in the dyslexic sample (28 children) compared to a control group (33 children), and that in 16 dyslexic children (57%) it was 2 standard deviations above mean. Unlike normal readers, on average the dyslexic group reported the symptoms investigated in 6 of the 9 questions of the CISS questionnaire. Of these, two questions corresponded to the items S2 and S4 of our questionnaire. Contrary to the AAP-DD, CISS score did not correlate with the reading rate. To be noted that, contrary to the AAP-DD, the CISS is not specific for dyslexia.

These aspects highlight the role that the visual signs and symptoms specific of dyslexics (and expected to depend on fine alterations in the perceptive and motor domain) has in preventing from reading fluently.

The higher prevalence of recent and actual specific visual/visuomotor problems in the dyslexic sample suggests that (taken together) some of the symptoms and signs investigated by the questionnaire may predict the onset of a reading disability before the third school grade (which is the age at which the diagnosis of dyslexia is generally made). Of the signs and symptoms, those involving the visual domain seem the most predictive of the reading disability.

In summary, the AAP is a mathematical approach aimed at providing a suggestion on the clinical problem before the diagnostic phase

takes place. In this respect the AAP is more effective compared to the conventional collection of information about the patient's medical history, since it is able to quantify and characterize the predisposing factors as found in relatives and the actual visual problems reported by the subjects in their everyday life. An additional advantage is that it is suitable not only to the specialized doctors but also as a screening pre-test for optometrists or general practitioners.

The present investigation suffers from two main flaws: first, the recruited samples were small. Indeed, as an exploratory study small samples were deemed sufficient to probe the potential of this approach. Considering the results obtained, replicating the experiment with larger populations is the intent of the authors.

In addition, the predominant role of the visual function found in the study may be biased by the recruitment criterion of the patients: dyslexics who participated in the experiment were those sent us by the neuro-psychiatrist who suspected a visuoperceptive alteration. Probably, different recruitment contexts will determine different outcomes and the effect of the section S may turn out to be less prevalent.

5. CONCLUSIONS

Preliminary investigations suggest that the AAP is a promising inexpensive and user-friendly solution to screen subjects at risk for developmental dyslexia at the beginning of primary school. In addition to the diagnostic data, it provides an early and more comprehensive overview of the clinical condition. Finally it may reduce the use of instrumental examinations, thereby the healthcare expenditure. Further in-depth analysis are necessary to test the AAP-DD in a large (and more heterogeneous) sample of dyslexics. Recruiting persons not referred to a service of Neuro-Ophthalmology may help reduce the confounding effects previously mentioned.

CONSENT

All authors declare that written informed consent was obtained from the patients' legal guardians for publication of these data.

The parents of all subjects were contacted by phone and a written informed consent was obtained after explanation of the aim, nature and possible consequences of the study.

ETHICAL APPROVAL

All authors hereby declare that all experiments have been examined and approved by the appropriate ethics committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

All applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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