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Predicting reading development. Visual attention in predicting individual risk for dyslexia

-abstract-

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CONTENT

KEYWORDS

Visual-spatial attention; reading development; visual search; dyslexia; predicting reading development; visual attention span; serial visual processing; parallel visual processing; phonological processing; reading acquisition; dyslexia risk factors; dyslexia protective factors; bimodal intervention in dyslexia.

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Introduction

Acquisition of reading opens the path to knowledge and educational success. It is a condition for future employment and social position (Peng et al., 2022). Consequently, learning to read is seen as the most critical achievement in primary school (Pfost et al., 2014). Nowadays, imagining a child's future without acquiring reading skills is difficult.

There is significant variability in the acquisition of reading skills ability during school age. The level of decoding skills is evaluated in all alphabetic languages based on the speed and accuracy of word decoding (Share, 2021). Reading will always be challenging for some children, no matter how much literacy training they receive. The condition of an individual whose decoding skills are at the lower end of the reading skills curve, determining that the child experiences great difficulties or impossibility in decoding a text, is called dyslexia. It represents a school failure risk and undermines the affected children's life project. Evidence shows that failing to address the problems of children with learning disabilities is associated not only with poor academic performance but also with socio-emotional effects like low self-esteem, higher rate of antisocial behaviour, homelessness, and even suicide (Grigorenko, 2006; Siegel, 2012; Zakopoulou et al., 2013).

Research on dyslexia focused on finding early signs that could help prevent dyslexia. Most evidence shows that predictors of dyslexia are similar regardless of the orthographic complexity of the language (Caravolas, 2005; Caravolas et al., 2012a; Moll et al., 2014). Various causal theories demonstrated the role of causal factors as predictors of learning-to-read development. The reading impairment literature was dominated for about forty years by two theories: the theory of the phonological deficit and the theory of the double deficit comprising the rapid automatised naming (RAN) deficit. During the last 20 years, more attention has been paid to visual processing deficits that could interfere with the early development of reading skills. Most studies focused on the variables that predict reading acquisition have not included visual processing tasks, phonological skills, or RAN tasks.

More specific data is needed on factors determining the early development of reading skills. The evidence on the relationship between the teaching method and orthographic complexity in acquiring reading skills must be more consistent. (Castles et al., 2018; Torgerson et al., 2006; Wyse & Styles, 2007).

Romanian is a shallow language, like Italian, Swedish, Greek, and German. The teaching of reading in most of these languages is based on a systematic sublexical approach (Fleischhauer et al., 2021; Kwok et al., 2017) due to the regular orthography that permits serial decoding of the written word. Romanian has a particular method of teaching based on a synthetic, global reading strategy, an adequate method for higher grain orthographies (see Goswami, 2008; Wimmer & Goswami, 1994 for the grain size theory).

This research aims to test a series of models for predicting reading development in a sample of children literate in Romanian, a language with transparent orthography. Objectives:

1. to identify the specific cognitive profile of those who meet the diagnostic criteria for dyslexia,
2. to identify protective factors favouring reading ability development in children at risk of dyslexia.

In this paper, the mechanisms and factors underlying learning reading, dyslexia as the lower part of the distribution of reading skills, and the hypothetical mechanisms underlying their deficit will be analysed in the first part. The importance of early prediction of the risk of dyslexia and the existing literature will be discussed. Part two includes a description of four studies: a meta-analysis drawing on existing studies of visual attention in processing written text and in the development of text decoding skills; two studies of reading level prediction; a study of the effectiveness of an intervention protocol based on a combination of attention training and visuospatial working memory, and a time-imposed reading training. The final chapter contains a series of general conclusions and considerations from the research.

Chapter I- Introduction and Theoretical Background. The following topics are analysed: *Models of reading acquisition* - describes the evolution of explanatory models of reading acquisition over the developmental period. The stage models proposed by U Frith, Seymour, and March (Frith, 1985; Marsh et al., 1981; Seymour et al., 2003; Seymour & Macgregor, 1984) are mentioned. The neuropsychological model of "brain area recycling" (Dehaene & Cohen, 2007) during learning to read is analysed by presenting research data supporting this theory. This model is important because, on the one hand, it describes the brain mechanisms involved in learning and the peculiarities of these areas. On the other hand, it explains several issues observed in children who show atypical development throughout the literacy process. This chapter analysed the evolution of computational models, which allow the simulation of the cognitive processes underlying the decoding of written text. Ample space is given to the CDP model (The Connectionist dual processing model), as this model (Perry et al., 2014; Ziegler et al., 2014) has allowed the simulation of reading learning and the influence that a series of deficits at the phonological or visual level, can have on the process of reading automation. Computational models are presented. Another model presented here is the MTM -Multiple-trace memory model of reading - based on the hypothesis of a deficit in parallel processing of visual stimuli with implications for dyslexia. The influence of spelling complexity on reading learning has also been examined in this chapter, given the evidence for differences in the duration of reading acquisition in transparent vs. opaque languages. The case of Romanian with its orthographic features is also analysed here.

Neurocognitive factors influencing text decoding ability - reviews existing evidence on various neurocognitive factors associated with the acquisition level of ability to decode written text. The types of tasks used to assess these skills and data supporting the role of phonological skills, particularly awareness of phonemes that form word structure, are reviewed. There is some evidence that it is not a phonological representation that is impaired in children who are poor readers, but access to these representations is associated with reading level. This chapter reviews the existing evidence on the association between Rapid Naming (RAN) and reading level and the research that has explained this phenomenon. Executive functions and how they may intervene in reading acquisition are discussed. Of these, verbal fluency, a measure of lexical access, processing speed, and working memory, is specifically examined, for each of which there is evidence that they are related to variations in the level at which reading ability develops. In this chapter, several issues related to visual attention and visual processing efficiency are examined, and evidence supporting a relationship with the level of reading ability is reviewed. Among these, there is evidence for a relationship between the efficiency of visuospatial orientation and reading ability, with poor readers being identified as having a reduced ability to reorient attention in the visual field, a tendency to orient attention predominantly to the right half of the visual field, neglecting the left (Facoetti et al., 2006; Sireteanu et al., 2005), a tendency to take an atypical approach in visual stimulus search tasks, giving priority to details before a global analysis of the visual field (Franceschini, Bertoni, et al., 2017). There is also evidence for a relationship between the ability to process stimuli in rapid succession and the reading level. Two experimental paradigms have been used: attention blink (related to the physiology of action potentials in retinal cells) and temporal order judgment (based on tasks to identify the order of presentation of fast sequential stimuli). One aspect of visual processing is the ability to process multiple visual stimuli in parallel, closely related to reading automation. This aspect has been assessed based on a "visual attention span" paradigm that examines the ability to encompass the attentional field and process multiple stimuli concurrently (Bosse et al., 2007). At the end of this chapter, data are presented on another factor related to reading acquisition: the efficiency of grapheme-phoneme conversion and the phenomenon of "binding" representing the ability to construct a multimodal construct that contains visual and auditory features but is perceived as a unit. There is evidence that the time window for constructing these auditory-visual bindings would be much longer for poor readers.

Dyslexia -The data currently available on the aetiology of this disorder are presented. This chapter presents dyslexia as a specific reading disorder defined based on the dimensional aspect of reading acquisition. Data on the genetic causes of dyslexia are reviewed, specifying the relationship between dyslexia and some of the disorders that frequently occur in co-morbidity, with evidence for the involvement of shared genes. There are several causal theories based on neuropsychological mechanisms. These theories refer either to a series of alterations in the structural-functional organisation of some brain areas, in the case of those with atypical development, the magnocellular theory of dyslexia, or to deficits observed in other cognitive processes: the phonological theory of dyslexia, the double deficit theory (phonological and preoccupation with a series of stimuli, RAN test), but also deficits in visual attention resulting in reduced efficiency of processing the visual stimulus (the written word). The temporal sampling framework is also a neurophysiological theory that describes an altered activation pattern of neurones involved in processing written text in people with dyslexia (Goswami, 2011).

Today's accepted model is multisensory, as several studies have shown that not all dyslexics have a single deficit to establish a single sensory determination. At the same time, not everyone with dyslexia has the same cognitive profile. This observation has consequences both at the theoretical level, linked to the foundation of causal theories, and at the level of clinical practice, when it is necessary to make a functional diagnosis to establish an intervention method.

Chapter II Research Objectives.

The aims of the research were:

1. To review and summarise the data on the association between visual attention skills and reading development;

2. To test several cognitive models for predicting the level of reading skills development, including in the analysis, in addition to the traditional variables related to language skills, two visual attention tasks. The research aimed to extend the findings of previous prediction studies that were based on selected children from families at risk of dyslexia;

3. To identify the predictors tapping on the early (phonological) stage of reading acquisition and distinguish them from predictors tapping the lexical stage of reading.

4. To test a bimodal intervention for dyslexic children designed to simultaneously stimulate phonologic and visual skills as a modality to enhance those skills and facilitate interconnections between visual and language skills.

Chapter III – Original Research Contributions presents four studies.

Study 1 - The Role of Visual Attention In Reading Development- A Meta-Analysis

The present study reports a systematic meta-analysis, an overall approach that allows one to obtain a pooled estimation of the magnitude of this relationship and counters the low statistical power of small studies. Additionally, we investigated the impact of orthographic depth and stage of reading acquisition on the relationship between reading proficiency and visual-attentional skills. According to the dual-route model of learning to read, word recognition evolves from an analytical strategy to a global one. This could involve a change in visual attentional processing strategies, a prediction that this study allows us to examine. A secondary goal was to evaluate the extent to which variability in the size of the effect of the relationship between reading proficiency and visual-attentional skills is affected by several potential moderator variables: orthographic depth, age, and type of task used to measure visuospatial attention. Finally, we also evaluated whether differences in this effect size were related to the type of study: correlational or group comparison (people with dyslexia vs. typically developing readers).

Objectives of the study. The main goal of this study was to estimate the strength of the relationship between reading proficiency and visual-attentional skills. The hypothesis of the study:

Hypothesis 1: There is a significant association between reading acquisition and visual attention involved in text processing;

Hypothesis 2: There are variations in the role of the two types of visual processing (serial or parallel) during the stages of literacy acquisition;

Hypothesis 3: There are variations in the role of visual attention related to the orthographic depth of the literacy training;

Hypothesis 4: The association between visual attention and reading level can be found in studies that evaluated attention skills before the onset of literacy training. To assess the possible causal role of visual attention skills impairment in dyslexia, in the General Discussion, we have considered two types of studies: those that are based on an intervention for reading optimisation and those that measured visual skills before the onset of literacy training, and we analysed whether or not the existing findings support the hypothesis that visual attention deficits can play a causal role in dyslexia.

Method

Search strategy. The review was designed following the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)(Moher et al., 2010). The included studies were identified by searching the PsycInfo, Medline, Web of Science and ERIC databases up to late December 2020, using a combination of search terms related to visual attention (*visual-spatial attention* OR *visual search* OR *visual attention span* OR *visual attention orientating* OR *visual attention*) crossed with *dyslexia* OR *reading development* OR *reading acquisition*. After this, a manual search was conducted in some journals. *Dyslexia, Scientific Studies of Reading, Reading and Writing, Annals of Dyslexia, Journal of Learning Disabilities* to identify studies that included data relevant to our study but were not focused on attention issues; 15 additional studies were found.

Study selection**.** We included all studies that examined the relationship between visual spatial attention and reading development, published in English before 31 December 2020. The criteria for study inclusion were the following: studies that included populations of school age (the mean age of the group was less than 18 years) with an alphabetic language and a left-to-right writing direction. Of the eighty-four effect sizes included in the meta-analysis, 21 were based on correlational studies, using unselected samples, for a total number of 2863 participants and sixty-three groups of children with dyslexia with typical readers compared, for a total number of 3914 participants.

Data collection and coding procedure.

A broad set of variables were collected for inclusion in subsequent analysis.

Type of effect size. The analysis included two kinds of effect sizes: one based on group differences between good and poor readers and the other based on the correlation between visual attention and reading performance measured in unselected samples of children.

Orthographic depth. The orthographic complexity of the language of reading instruction was evaluated as a moderator variable.

Sample Characteristics: Age. The mean age of the samples (in years, using two decimals) was coded. The mean age range was four years (pre-literate samples) to 16.41 years. Due to the non-normal distribution of the variable, it was not considered as being continuous;

instead, it was transformed into a categorical variable as follows: *pre-literates* (≤6 years of age), *beginners* (7-9 years), and *advanced readers* (> nine years of age).

Attention task. The type of attention task was evaluated as a moderator variable with two levels based on the type of visual processing required. *Visual-spatial orienting* included 28 studies based on the Posner cueing task, the bisection task, and a visual search task that explicitly required serial processing of the stimuli. The other category, *Visual attention span* (VAS), included 38 studies based on the visual attention span task (see Frey & Bosse, 2018, for a review), which is considered for indexing parallel visual processing in reading.

Statistical analysis**.** ProMeta 3 (Internovi, Cesena, Italy) was used to perform statistical analyses on the effect sizes of the included studies.

Evaluation of the mean relationship between reading and attention across all studies. Eighty-four effect sizes were included in the analysis. As 21 of the 84 effect sizes included were based on small samples, we considered Hedge's *g* appropriate to estimate the overall effect size because, for samples of fewer than 20 participants, it outperforms Cohen's *d* to prevent bias (Hedges, 1981). Random-effects modelling was used as it assumes that the true effect is not identical for all studies; its goal is to estimate the mean of a distribution of effects (Borenstein et al., 2007).

Moderator analyses**.** Four moderator variable analyses were performed to evaluate the relevance of the moderator variables to the relationship between visual attention and reading proficiency: type of effect size, orthographic depth, age group, and visual attention task. For these, the studies were grouped into subsets based on the categories defined by the moderator variable. An overall estimate of the effect size and a 95 % confidence interval were provided for each level of the moderating variable.

Analysis of the moderating effect of age on effect sizes associated with orthographic depth, attention task, and type of effect size. In three additional analyses, we investigated the moderating effect of the age of the participants on the relationship between attention and reading proficiency for different levels of orthographic depth, type of attention task and type of effect size. These analyses could provide information about the evolution of the association between attention and reading proficiency during reading development.

Results

The mean effect size of the relationship between reading and attention**.** Eighty-four effect sizes were combined. The variability between studies was high. Q(83) = 291.83, $p<.001$, I2 = 71.56 (Higgins et al., 2003), indicating that the variance in effect sizes was not exclusively due to sampling errors. Therefore, the random-effects model was used to combine individual effect sizes. The overall mean estimate of effect size was both large and significant: k=84, Hedge's g = -.98; 95% CI [-1.08; -.88], $p<.001$, favouring the typical reader group (Table 1).

The overall analysis results are reported, as are the results of the evaluations of the role of moderator variables on the relationship between reading and visual attention skills. Moderator variables include the type of effect size, orthographic depth, age group and type of experimental attentional task (see text for details)(Gavril et al., 2021).

Moderator analyses

Further meta-analytic subdivisions of the overall sample were performed, considering the low homogeneity of the studies included in the analysis.

Type of effect size. The overall effect size was calculated by combining two data types: correlational and based on group differences (good vs. poor readers). When evaluating the differences between the two types of studies, we found that the effect size of the studies that evaluated differences between groups defined by reading performance was significantly larger ($Q_{between}(1) = 4.71$, $p=.042$) with respect to those obtained by summarising correlational data (Table 1).

Table 1

The Results of The Meta-Analyis (Based On 84 Samples) Examining The Magnitude Of The Relationship Between Reading Skills And Visual Spatial Attention.

Moderator levels			**Effect size**			**Heterogeneity**					
	k	N	Hedge's *g*	95% CI	*p*	Q_{within}	*df*	*p*	I^2	$Q_{between}$	*p*
Overall effect											
	84	6777	-.98	[-1.08; -.88]	<.001	291.83	83	<.001	71.56	-	-
Moderator analysis											
*Type of effect size**											
Group difference mean effect size	63	3914	-1.02	[-1.14; -.89]	<.001	241.35 1	62	<.001	74.31	4.71	.042
Correlational mean effect size	21	2863	-.85	[-,95; -.75]	<.001	28.51	20	.098	29.84		
*Orthographic depth**											
Opaque	47	4674	-1.03	[-1.14, -.92]	<.001	150.23	46	<.001	69.38	4.32	<.05
Transparent	37	2103	-.84	[-.98, -.69]	<.001	90.88	36	<.001	60.39		
*Age group**											
Pre-literacy	10	1400	-.66	[-.77, -.54]	<.001	4.71	9	.859	0.00	21.30	<.001
Beginner	23	2279	-.88	[-1.03, -.74]	<.001	50.28	22	.001	56.25		
Advanced Readers	51	3098	-1.07	[-1.21, -.93]	<.001	192.61	50	<.001	74.04		
Experimental task											
Visual-spatial att.	28	1598	-.81	[-.95; -.67]	<.001	47.30	27	.009	42.92	6.90	.009
VAS	38	3471	-1.06	[-1.17; -.94]	<.001	97.76	37	<.001	62.15		

k = number of studies; N = total sample size; CI = confidence interval; Q_{within} = within-group homogeneity of variance; I^2 = proportion of real variation between studies inside sub-group; $Q_{between}$ = between-groups homogeneity of variance. *Analyses performed on all the selected studies

Orthographic depth. We evaluated the moderator role of orthographic complexity by comparing studies based on the participants' language. Forty-seven effect sizes relating to opaque languages and 37 effect sizes relating to transparent languages were included in the analysis. As the results show (Table 1), the relationship between reading and visual attention skills is slightly but significantly stronger for deep orthographies when compared to transparent orthographies: $Q_{between}$ (1): 4.32, $p<.05$.

Age group. We investigate whether the magnitude of the effect sizes of individual studies varies in relation to the age group of the participants. As seen in Table 1**,** the strength of the association between visual attention and reading shows a clear trend of increasing with age, such that the mean effect size is larger for older readers when compared to pre-readers ANOVA $Q_{between}$ (2) = 21.30, $p<.001$.

Attention task. The magnitude of the relationship of reading with each type of visual attention task is high and significant. When the subgroup of studies based on visual-spatial attention tasks was compared with studies based on the visual attention span task, we found an estimated mean effect size slightly, but significantly higher for the latter $Q_{between}$ (1) = 6.90, $p<.01$ (Table 1). This result indicates that the type of task used to evaluate visual attention is a moderator that partially explains the heterogeneity of the studies included in the overall analysis.

Age group analysis differentiated by orthographic depth. We analysed the effect of age on the relationship between reading and attention skills for studies aggregated based on orthographic depth. Interestingly, the mean effect sizes were similar at the preliteracy level in the two orthographic groups (transparent and opaque); after that, the mean effect size progressively increased among older children reading in a deep language ANOVA $Q_{between}$= 17.71, df = 2, $p<.001$, while, as shown in Table 2, the mean effect size across age groups for shallow languages did not significantly change ANOVA $Q_{between}$ (2)=5.27, p =.072.

Table 2

The Moderator Effect Of Age (Pre-Literate, Beginner And Advanced) On The Magnitude Of The Relationship Between Reading Skills And Visual Spatial Attention For Different Subgroups Of Studies Based On Specific Study Characteristics: Orthography, type of Visual Attention Task, Type of the Reported Effect Sizes (Gavril et al., 2021).

			Effect size			**Heterogeneity**					
Sample of studies	*k*	N	Hedge's *g*	95% CI	*p*	Q_{within}	*df*	*p*	I^2	$Q_{between}$	*p*
Studies related to transparent orthographies											
Pre-literacy	6	551	-.63	[-.79; -.46]	<.001	3.47	5	n.s.	0.00	5.27	.072
Beginner	10	524	-.78	[-1.07; -.49]	<.001	21.20	9	.012	57.34		
Advanced Readers	21	1028	-.96	[-1.19; -.73]	<.001	65.48	20	<.001	69.44		
Studies related to opaque orthographies											
Pre-literacy	4	849	-.68	[-.83; -.53]	<.001	1.03	3	n.s.	0.00	16.81	<.001
Beginner	13	1755	-.94	[-1.09; -.78]	<.001	24.74	12	.016	51.50		
Advanced Readers	30	2070	-1.14	[-1.30; -.98]	<.001	98.39	29	<.001	70.52		
Studies that used visual-spatial orienting tasks											
Pre-literacy	4	273	-.74	[-1.01; -.47]	<.001	0.89	3	n.s.	0.00	3.18	.204
Beginner	9	751	-.67	[-.83; -.52]	<.001	8.26	4	n.s.	3.20		
Advanced Readers	15	574	-94	[-1.20; -.69]	<.001	32.89	10	.004	56.64		
Studies that used visual attention span tasks											
Pre-literacy	2	257	-.78	[-1.04; -.51]	<.001	0.00	1	n.s.	0.00	6.58	.037
Beginner	9	1305	-.93	[-1.10; -.77]	<.001	14.16	8	n.s.	43.50		
Advanced Readers	27	1909	-1.14	[-1.29; -.99]	<.001	82.83	26	<.001	70.67		
Studies based on group differences effect size											
Pre-literacy	4	510	-.64	[-.83; -.45]	<.001	1.23	3	n.s.	0	13.10	.001
Beginner	13	767	-.87	[-1.13; -.61]	<.001	32.50	12	.001	63.08		

Advanced Readers	46	1288	-1.09	[-1.25; -.94]	<.001	191.86	45	<.001	76.55		
Studies based on correlation effect size											
Pre-literacy	6	890	-.67	[-.80; -.53]	<.001	3.44	5	n.s.	0.00	8.04	.018
Beginner	5	1512	-.91	[-1.06; -.76]	<.001	15.27	4	n.s.	41.08		
Advanced Readers	10	461	-.96	[-1.17; -.76]	<.001	.70	9	n.s.	0.00		

k = number of studies; N = total sample size; CI = confidence interval; Q_{within} = within-group homogeneity of variance; I^2 = proportion of real variation between studies; $Q_{between}$ = between-groups homogeneity of variance.

Age group analysis was differentiated by the attention task used. When analysing the effect of age on the relationship between reading and attention depending on the type of attention task, we found a significant ($p<.05$) upward trend with age for the visual attention span and also non-significant differences between age groups for visual-spatial attention-orienting tasks (Table 2). This result suggests that the association between reading and multi-element processing skills increases with age during the reading acquisition period. Interestingly, it does not support an association between visual spatial orienting tasks and any specific stage of reading development: the magnitude of the relationship between visual attentional processes involved in serial visual analysis seems unchanged across age groups.

Age group analysis is differentiated by the type of effect size. The moderator effect of age was confirmed regardless of the type of effect size, the estimated mean effect size revealing an upward trend, both in correlation and group difference studies. In particular, when only studies that evaluated the effect size of group differences were analysed, the mean effect size of the studies clustered by age groups showed a strong and significant upward trend Q between (2) = 13.10, p = 0.011 (see Table 2), showing that an initial visual skills gap between good and poor readers, quantified by a medium effect size at the preliteracy level, increases significantly until the end of compulsory schooling age.

Discussion

Based on a quantitative meta-analysis, this study examined the visual-attentional processes involved in text decoding during the developmental period. The results confirm a strong and significant relationship between reading level and visual attentional skills involved in efficiently processing the written word (*Hypothesis 1*). This association's estimated overall effect size is larger than g = -.90 in favour of typical readers, even after excluding outliers.

Spelling complexity influences the relationship between visual attention and reading skills and is significantly greater for children learning to read in languages with deep spellings. This finding is consistent with the results of previous studies on differences determined by the character of the language in which literacy is learned between English (deep spelling) and Italian (shallow spelling) university students while performing reading-related tasks (Paulesu et al., 2001). This work confirms the hypothesis that, although the reading process is based on universal mechanisms based on common brain circuits (D'Mello & Gabrieli, 2018), there are differences in brain activation patterns: Italian readers show more robust activation in areas related to phonological processing, probably indicating a higher proportion of phonological procedures in the decoding process. Our study suggests differences in processing modes between texts based on spellings with different degrees of complexity are present as early as the early stage of visual attentional processing of the written word (*Hypothesis 3*).

Our study aimed to investigate specific patterns that describe how the relationship between visual processing performance and reading skills evolves during reading development. An estimated overall effect size (g =-.66) indicated that reading proficiency is moderately associated with visual attention skills (Table 1) was obtained from studies that evaluated visual-spatial attention skills in kindergarten children. We estimate that a mean effect size of g = -.64 quantifies the gap between prereading attention skills in studies comparing children with dyslexia (or family risk of dyslexia) with typical readers (Table 2). This gap between spatial attention skills of readers with different levels of reading skills, which precedes the start of literacy training, supports the hypothesis of a delay in attention-orienting maturation in dyslexic children (White et al., 2019) and also supports the causal role of the visual-attention deficit in dyslexia (*Hypothesis 4*). Our data show that after the onset of literacy training, the association between visual attention and reading skills increases progressively and becomes significantly stronger in readers after nine years of age (in the mature reader group g = -1.07). Evidence from this analysis supports *Hypothesis 2*. This upward trend could be explained by differences in attention maturation between good and poor readers during reading development. Longitudinally, more data would be needed to investigate the evolution of visual attention skills during literacy acquisition.

A relevant aspect that emerged from this analysis is the age-specific diversity in the pattern of association between visual attention skills and reading development as a function of spelling depth. Thus, while the magnitude of the association between visual skills at preliteracy age and reading was similar regardless of orthographic depth, two different development patterns emerged after the onset of the reading training: For readers of transparent languages, the change was not significant. On the contrary, for those learning to read in an opaque orthography language, we found a significant increase with age in the strength of the association between attention skills and reading level (Table 2). This difference suggests that, relative to orthographic complexity, visual word analysis strategies evolve differently.

A wide variety of tasks were used to investigate visual attention. The potential moderating influence of the types of tasks used in assessing visual attention has been considered, and their correspondence to theoretical models (Gavril et al., 2021; Ans et al., 1998; Facoetti et al., 2006). The data show that the magnitude of the relationship between parallel processing ability (PPA) and reading skills increases slightly with age (from moderate to high in pre-school age to an overall estimated high effect size in the beginning and advanced readers). This growing trend indicates a strong influence of visual attention ability from the early to mature stages of reading development when words are decoded globally. A similar upward trend (although not significant) was found for tasks that assessed focused spatial visual attention. This trend suggests that the association between decoding skills and effective visual-spatial orientation may not be limited to the early stage of reading acquisition. On the contrary, it may continue influencing reading development even in expert readers.

When studies based on comparisons between good and poor readers were analysed separately, we observed that the difference between the two groups in the relationship between reading proficiency and visual attentional processing increased significantly with the increasing age of the participants (Table 2). This finding supports the hypothesis that the initial delay in the development of visual attention found in preschool children may not diminish during learning to read. In contrast, with age, differences in visual attention diminish.

Theoretical Implications.

The results of our meta-analyses are consistent with a dual model of visual processing of text, which involves both serial and parallel processing during all stages of reading learning. Our study provides further evidence in support of models of attentional involvement in serial and parallel string analysis in decoding (Ans et al., 1998; M. Bosse et al., 2015; Bosse et al., 2007; Franceschini et al., 2012; Hari & Renvall, 2001), highlighting the complementarity of their roles in reading. The results of our analysis support continuity in terms of the involvement of attentional processes in the serial visual analysis of letter strings (Gavril et al., 2021). This finding extends from the initial stage of learning to read, when the word is segmented into graphic components (Facoetti, Zorzi, Cestnick, Lorusso, Molteni, Paganoni, Umilta, et al., 2006; Perry et al., 2014) until the advanced stages of reading, when attentional processes facilitate saccadic regulation and reading fluency (Hautala et al., 2020). Similarly, parallel processing of the letter sequence contributes to developing an orthographic lexicon in the early stages of learning to read. Later, parallel letter processing contributes to whole-word recognition (Ans et al., 1998). There is no fixation point on every word. Some words are skipped during reading because saccadic planning is influenced by a range of low-level information (such as word length and proximity of the initial fixation to the beginning of the word) and holistic linguistic properties of words, such as word frequency (Choi & Gordon, 2014; Reichle et al., 2012). This particularity of the visual analysis indicates the importance of parafoveal previewing, while the word in the foveal position is decoded by parallel processing.

This preview at the edge of the attentional field provides the information needed for strategic reading adjustment by skimming parts of a text, allowing skipping over parts of sentences that provide redundant information (Hautala et al., 2020). Therefore, a deficit in visual attention could explain the abnormal eye movements observed in dyslexic children during reading.

The data from this meta-analysis, together with the results of previous work, including several training studies aimed at improving parallel processing/serial processing or facilitating the transition from one to the other, provide strong evidence that visual attention involved in serial and parallel processing of letter strings may play a critical role in all stages of reading development (Gavril et al., 2021).

Study 2 - The Contribution of The Visual Processing Skills to Early Reading Acquisition Prediction Models. A Preliteracy Prediction Study

There is a rich literature on predictors of reading skills acquisition; different approaches were used in terms of choice of study participants and instruments used. Most of the longitudinal studies were conducted on at-risk family children *(e.g. Thompson et al., 2015; Franceschini et al., 2012),* while only a few studies (Caroll et al., 2016) investigated the contribution of those predictors on reading in typically developing populations. Our study aimed to test a prediction model based on a sample from an unselected population of Romanian children. Such data would be needed to understand better the contribution of the visual scanning process on reading acquisition in a transparent language.

Many studies (Puolakanaho et al., 2008; Lyytinen et al., 2015; Georgiou et al., 2008; Davidse et al., 2011; Smythe et al., 2008) included in the prediction study only language-related skills and did not consider the role of visual abilities. Other studies included a composite measure of executive functioning (go-no-go task, heads-toes-knees-and shoulders, visual search task, a sustained attention efficiency score, and a working memory score). The data obtained did not permit one to disentangle the role of each of these variables to see what type of executive skill significantly impacts the predicting model. Our approach adopted an information processing perspective by considering the representations and computations that operate on them to obtain the framework for reading development (Simon, 1962). Visual processing skills were considered a specific component in the prediction model besides the phonological and lexical access skills. We decided to include in this study, in addition to the classical WISC-IV symbol search, another visual serial search task that was inspired by existing evidence on the importance of exterior letters in identifying a written word (Eriksen & Eriksen, 1974; Johnson & Eisler, 2012; Lawton, 2016b; Peressotti & Grainger, 1999; Scaltritti et al., 2018). Phonemic fluency was used to investigate lexical access instead of the RAN task. Verbal fluency (phonemic) is generally associated with frontal lobe functioning and develops throughout childhood and adolescence (Cohen et al., 1999). It also involves the development of executive functioning, which has been associated with reading competency (Varvara et al., 2014). We included three phonemic fluency tasks to evaluate lexical access, corresponding to the access to phonological lexicons in CDP++.

Study goals

The aims of this study were: -to identify the predicted pre-reading cognitive profile of children with reading deficits at the end of the second grade of elementary school and

-to identify the protective factors of reading development and the main cognitive predictors of low progress in reading.

The hypothesis of the study:

Hypothesis 1: There is a prevalent cognitive profile of low decoding achievement in children regardless of the reading pathway considered;

Hypothesis 2: Pre-reading visual attention skills reliably predict low reading achievement;

Hypothesis 3: Variations in pre-reading cognitive profiles are related to progress in reading for the children considered at-risk for dyslexia based on the early reading assessment.

Study 2a – Cognitive Predictors of Dyslexia Individual Risk

The present study aimed to investigate, via logistic regression models, Romanian children's behavioural preliteracy predictors of reading acquisition. To reach the study goals, we followed a group of Romanian children from the preparatory year of elementary school. They were assessed in some crucial early predictors through the first and second grades. The predictors that were considered concerned three main aspects, i.e., phonological skills, visual processing skills, and phonemic fluency, i.e., the ability to produce as many examples as possible of words which begin with a given phoneme. In the study, we focused on the speed measure for evaluating reading ability, consistent with that, in regular orthographies, the most reliable measure of reading acquisition is related to speed (Landerl & Wimmer, 2008). However, the error numbers were included in a composite measure of reading skills level to avoid the speed-accuracy trade-off that characterises many struggling readers. We used a composite measure of reading efficiency by calculating the reading speed based on correct decoded syllables. This study aimed to identify the specific profile of low reading achievement related to each type of reading task: nonword reading, word reading, and text reading. We used a correlational study design to model individual risk prediction based on logistic regression.

Method

Participants

An unselected sample of one hundred and nineteen children (56% females) were followed from grade zero (the first year of compulsory schooling in Romania) to grade 2 in three elementary schools in Bistrița, Romania. These children were part of a larger group of 140 children examined in the preparatory grade of the primary school, of whom 21 could not be considered due to missing data. We used G*Power (Faul et al., 2009) to calculate the minimum sample size necessary for a logistic regression-based statistical analysis. Considering the 0.17 odds ratio (based on a cut-off point set at the 15^{th} percentile), the minimum sample size is N=36.

The age range of the children at the beginning of the study was between 6y;1m and 7y;6m (M = 79.50months; SD = 4.16). The sociocultural level was typically average, with a few cases classified by teachers as disadvantaged (N = 7). No child presented intellectual weakness below the fifth percentile in the intelligence level measured with the Raven test (Raven, 2008). The study was carried out following the Declaration of Helsinki (1964), following the ethical guidelines of the Department of Clinical Psychology and Psychotherapy, Babes-Bolyai University of Cluj-Napoca, Romania. Data were collected with permission from the educational institutions the children attended. Explicit informed consent was obtained from the children's parents or legal tutors prior to participation.

Materials

The battery of predictors administered contained:

1. *Phonological awareness.* Phonological skills were evaluated based on three tasks following the method present in the test PAT-2 (Robertson & Salter, 2007): 1a) *last phoneme identification*; 1b*) phoneme blending*; 1c) *word segmentation*: All tasks were based on nonwords to assure a complete nonfamiliarity of children with the items

included. A composite score for phonological awareness was calculated as the sum of the z-standardised scores for the three subtests.

2. *Lexical access tasks*: The task required naming as many words as possible, beginning with a particular sound (either C, S, or P), in a one-minute time interval. Every word correctly found was scored 1 point; a composite score was calculated as a sum of the z-standardised scores for the three subtests.

3. *Visual processing efficiency* was evaluated with two tasks, as a composite score, calculated as the sum of the z-scores:

A visual search task that exploited the influence of the serial position effect (Carreiras & Grainger, 2004; Scaltritti et al., 2018; Tydgat & Grainger, 2009). It consists of 42 groups of visual symbols, including 2, 3, 4 or 5 items, organised on six rows (7 groups on each row). The task required identifying target symbol groups based on their initial and final elements, and the score was determined by the number of groups correctly identified in a 60-second interval (range of scores = 0-14).

Symbol search: the task is a speed visual processing task and is part of the Wechsler intelligence scale for children (*Symbol search,* WISC-IV, Wechsler, 2003).

4. *A phonological memory task* based on nonword repetition.

5. *Non-verbal cognitive abilities were evaluated using the Raven Coloured Matrices* test (Raven, 2003).

Reading tasks. Methods to measure reading skills have been inconsistent across the study steps, as the first step was completed while the alphabetical principle instruction was still in progress. Syllable (nonword) reading tasks, word, nonword, and text reading tasks were used to assess the level of reading skills acquisition. The examiner measured the overall time required by the child to read the material and the number of errors. A composite reading efficiency score was calculated to control the trade-off between reading speed and accuracy. The reading score was obtained as a ratio between the number of correct decoded syllables (the error number was subtracted from the total number of syllables of the test) and the time needed to read all the items (see Franceschini et al., 2013).

Procedures

Each child received a battery of cognitive and preliteracy measures in the January-February period of grade zero (Time 0). In November of the first grade (Time 1), the children were evaluated for a sub-lexical reading test (based on syllable reading). In April of the second grade (Time 2), the same children were assessed for nonword reading ability, word recognition and text decoding.

Statistical analysis

*Preliminary Data Analysis. T*he correlations between the measures for all tasks administered and their descriptive statistics for the group that could be tested in all sessions. All variables were significantly correlated with the two exceptions for the correlations of two predictors (sound blending and word segmentation) with the symbol search task that only approached significance.

Results

Based on each test reading score, the unselected sample of children was divided using a cut-off criterion of 1.5 SD below the mean. Separate logistic regression models were built for each type of decoding competence (non-word, word, and text reading) using a hierarchical procedure. As text reading was considered the most ecological test, a Receiver Operator Analysis (ROC) was performed for the main predictors included in the model.

Two models were specified for the sub-lexical pathway of decoding. Two predictors were found to be significant for sub-lexical reading skills in the first grade: Phonological awareness and Lexical access scores. Both uniquely predicted the probability of reading difficulties in the first grade. The effect size of the model was Cox & Snell R square =.23.

The estimated sensitivity of the model was <50%, indicating that a high percentage of positive cases remain unidentified.

Table 4

Prediction Models of the Sub-Lexical Reading Skills Level

	Syllable reading			**Non-Word reading Model 1**			**Non-Word reading Model 2**		
Variables	B(SE)	Odds ratio 95% C.I.	Wald Statistic	B(SE)	Odds ratio 95% C.I.	Wald Statistic	B(SE)	Odds ratio 95% C.I.	Wald Statistic
PA composite	-.971(.47)	.38 [.15, .95]	4.79*	-1.12(.36)	.33 [.16, .66]	9.95**	-	-	
Visual attention	-	-	-	-	-		-	-	
Lexical access	-1.33(.48)	.27 [.10, .68]	6.72*	-	-		-.81(.34)	.45 [.23, .88]	5.54*
Nonverbal IQ							-.64(.30)	.53 [.30, .95]	4.49*
Constant	-2.94(.59)	.05	26.73***	-2.12(.36)	.12	34.86***	-2.12(.34)	.12	38.0***

*p=.05, **p=.01, ***p=.001

Table 5

Classification Accuracy for the Sub-Lexical Reading Logistic Models

	Syllable reading	**Non-Word reading Model 1**	**Non-Word reading Model 2**
Sensitivity	47.4	0	11.1
Sensibility	97.0	100	99.0
Overall Percentage	89.1	84.9	85.7

With the NW reading test, we tested the predictors related to developing the phonological pathway of decoding in the third year of literacy training. When phonological awareness was introduced as a predictor, no other variable reached significance in the prediction model (see Model 1). The effect size of the model was low: Cox & Snell R square

=.11, and the prediction sensitivity was 0%, and none of the observed cases was predicted by the model in our sample.

A second prediction model was built starting with the lexical access, and the non-verbal IQ was also included in the model. The effect size of the model was low: Cox & Snell square R =.12, and the prediction sensitivity was 11%; a high percentage of positive cases cannot be identified.

One model was found to be significant for word reading skills level, while two models were found for text reading skills. Phonological awareness and Visual processing efficiency were significant predictors for all the models at the lexical level.

The word reading prediction model included two predictors: both phonological awareness and visual processing efficiency uniquely predicted the probability of word reading difficulty. The effect size of the model was Cox & Snell R square =.22. A model based on the same predictors, as we found for the word decoding level, was also significant for text reading.

Table 6

Prediction Models of the Lexical Reading Skills Level

	Word reading			**Text reading model 1**			**Text reading model 2**		
Variables	B(SE)	Odds ratio 95% C.I.	Wald Statistic	B(SE)	Odds ratio 95% C.I.	Wald Statistic	B(SE)	Odds ratio 95% C.I.	Wald Statistic
PA composite	-1.62(.56)	.20 [.07, .59]	8.97**	-2.74(.92)	.07 [.01, .39]	9.29**	-2.90(.90)	.06 [.01, .32]	10.13**
Visual attention	-.72(.33)	.49 [.25, .94]	3.20*	-.74(.26)	.48 [.28, .80]	7.18**	-.82(.28)	.44 [.26, .76]	7.56**
Phonological memory span	-	-					.82(.42)	2.26 [.99, 5.14]	4.14*
Constant	-2.94(.59)	.05	24.14***	-4.14(1.06)	.02	13.65***	-4.25(1.02)	.14	14.26***

*p=.05, **p=.01, ***p=.001

Table 7

Classification Accuracy for the Lexical Reading Logistic Models

	Word reading	**Text reading model 1**	**Text reading model 2**
Sensitivity	23.5	52.6	57.9
Sensibility	97.1	94.0	96.0
Overall Percentage	86.6	87.4	89.9

Phonological skills and visual processing skills uniquely predicted the difficulty of text reading. The effect size of the model was Cox & Snell R square =.35. As the assumption of the linearity of the logit has not been met, we tested another model by introducing another predictor. No collinearity problems were identified.

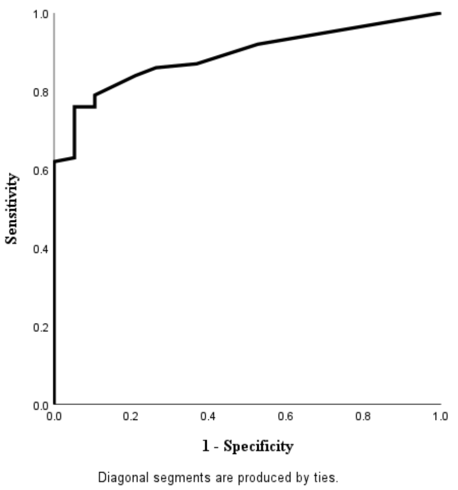
The second model to predict text decoding skills included three predictors: Phonological awareness, visual processing efficiency and Phonological memory span. The effect size of the model was Cox & Snell R square =.37. The total estimated prediction percentage was 89.9, based on our sample data. When the interaction between the predictor and the log itself was included in regression besides the predictors, none of the interactions were significant, indicating that the assumption of the linearity of the logit has been met (Hosmer et al., 1989).

The cut-off scores for each predictor are determined based on an ROC (receiver operator characteristic) analysis. Text reading scores were considered for the classification of reading performance. An ROC (Receiver Operating Characteristic) was conducted for each variable included in Model 1 to predict text reading. Sensitivity was plotted against false positive rates to quantify how well each predictor included predicted the reading outcome. The values for the area under the curve are presented in Table 7. The data showed that the cut-off value of -.92 (composite z-score) for phonological awareness would correctly identify 95% of the positive cases, and we would have to tolerate about 24% of false positives. Alternatively, a cut-off value of -.71 (composite z-score) for phonological awareness would correctly identify 89.5 of the positive cases, while the percentage of false positives would decrease to 21%.

Table 8

Characteristics of Predictors Concerning Reading Status Determined by Text Reading Scores

Predictor	**AUC**	**SE**	**95% C.I.**	**p**
Phonological awareness	.89	.03	[.83, .95]	<.001
Visual processing efficiency	.87	.04	[.79, .95]	<.001
Phonological memory	.51	.07	[.38, .65]	n.s.



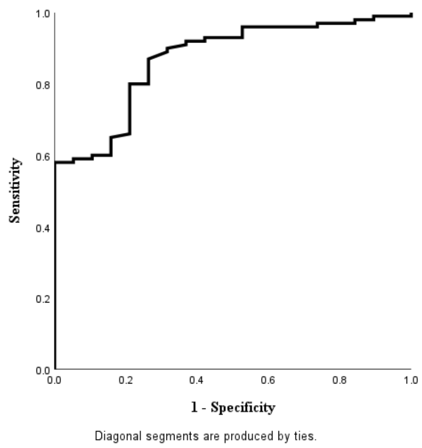


Figure 4. ROC Curve for phonological skills **Figure 5**. ROC Curve for visual processing skills

For the visual processing skills, a cut-off z-score of -.22 (composite z-score) would correctly identify 84% of the positive cases, while the percentage of false positives would be 35%. Alternatively, a cut-off z-score of -.49 (composite z-score) would correctly identify 78.9% of the positive cases, while we would have to tolerate 20% of false positives. Phonological memory was not considered a valid predictor based on our sample data.

Discussion.

The research was primarily focused on finding predictors of general reading skills in various stages of reading acquisition. Our study investigated the predictors of different reading tasks, all related to the final stage of compulsory reading training (the second grade of elementary school). The most interesting observation emerging from our data was the variations in the predictor patterns depending on the type of reading task considered a dependent variable. Therefore, our data do not support the hypothesis of a general cognitive profile that predicts all the processes involved in text decoding (*Hypothesis 1*). Other studies have found similar differences concerning various age levels throughout the reading development period (Thompson, Hulme, Nash, Gooch, Hayiou-Thomas et al., 2015). Our results suggest that various reading tasks (word, nonword, or text reading) involve variations in the underlying cognitive processes. These variations are reflected by the variations in the pattern of early predictors, all prerequisites for instrumental decoding skills. The data also suggest different processes are tapped by different predictors that sustain reading in relation to the stage of development and the pathway of decoding (phonological or lexical).

Although phonological skills are universal predictors regardless of the stage of reading development, a salient aspect is the presence of visual processing efficiency as a marker of the lexical stage prediction model for reading acquisition (visual skills reached significance only for word reading tasks and text reading). This result supports the hypothesis (see *Hypothesis 2*). of a relationship between visual processing and the efficiency of attention orienting within the letter string (Facoetti et al., 2001; Franceschini et al., 2012; Gori & Facoetti, 2015). Phonological skills, non-verbal IQ score, and lexical access are the variables that predict the first stage of decoding (syllable reading), and they predict about half of the poor readers at that time. Interestingly, no predicting model can detect children who fail to develop the sub-lexical pathway of decoding. During the second grade of elementary school, the main predictors are phonological skills or lexical access and non-verbal IQ score. However, these models do not reach an acceptable sensitivity threshold. This finding could be related to the teaching method, which prefers the global decoding approach and asks children with low progress in reading acquisition to return to a letter-by-letter strategy. The variations in the second-grade nonword reading skills are not related to the reading strategy but are determined by a problem-solving approach, as no syllabic strategy was learnt during the first two years of literacy training.

Phonological and visual processing skills are significant predictors of the lexical stage of decoding. The area under the curve in the ROC analysis was .89 for the phonological skills and .87 for the visual processing skills, both variables having good prediction power.

Study 2b – Predicting the Severity of The Reading Disorder

An important feature that influences the prognosis of dyslexia is the potential for improvement with the help of specific exercises. Response to therapy makes the difference between children who can make progress because they can get the motivation to continue to work hard, opposite to children who do not feel any improvement and whose academic trajectory is significantly influenced by their being 'dyslexic'. From a clinical point of view, the question of reading growth becomes of interest for children with a low acquisition rate during the first year of literacy training: we wonder how much progress we can expect and which cognitive profile characterises those children who register low or no progress. Another question is, what promotive factors prevent high-risk children from becoming 'low-achievers'?

This study aimed to individuate the cognitive profile of children with severe dyslexia according to their low progress rate. Our hypothesis (*Hypothesis 3*) was that a dual deficit: phonological awareness deficit, and visual processing efficiency deficit would indicate a high risk of severe dyslexia. We used a non-parametric statistic: *Fisher's exact test,* to estimate whether the relationship between the double deficit and the progress group is statistically significant. We used G*Power (Faul et al., 2009) to calculate the minimum sample size necessary to perform *Fisher's exact test.* Considering the proportions of double deficit children, the minimum sample size is N=32.

Another objective is to identify, based on the risk situation defined by the low scores on the first-grade evaluation, the promotive factors that allow the child to compensate and determine the evolution toward age-appropriate reading skills (Slomowitz et al., 2021).

Our hypothesis (*Hypothesis 4)* was that visual attention skills and non-verbal cognitive abilities were the factors that, besides phonological skills, influence the progress of early low achievers.

Method

Participants

Several participants of Study 2a were selected for Study 2b, as follows: A case-by-case analysis identified 12 children who performed poorly (<15°) at the first-grade evaluation but were included in the typically developing group after text reading performance at the end of the second grade. They were identified as the *Progress group* (N=12). Seven children with scores above 15 ° in syllable reading obtained low scores a year later on text reading. They were included in a *Low progress group* (N=18), together with 11 children who received poor scores in both evaluations T1 and T2.

A considerable corpus of research investigates the differences between good and poor readers. To our knowledge, no one has studied, so far, the differences between the profiles of children who, after a poor start, manage to catch up with good readers and those who, after a poor start, develop a reading disorder.

Procedure

The relationship between predictors and reading development was analysed, considering sub-lexical reading (first grade) scores and text decoding skills at the end of the second grade. When only the two groups of children at-risk for dyslexia were analysed separately, it was found that they were similar in the visual processing speed but different in the efficiency of the visual search processing. This finding suggests that differences between the groups in the visual processing efficiency (composite score) were entirely determined by the differences in the visual search process.

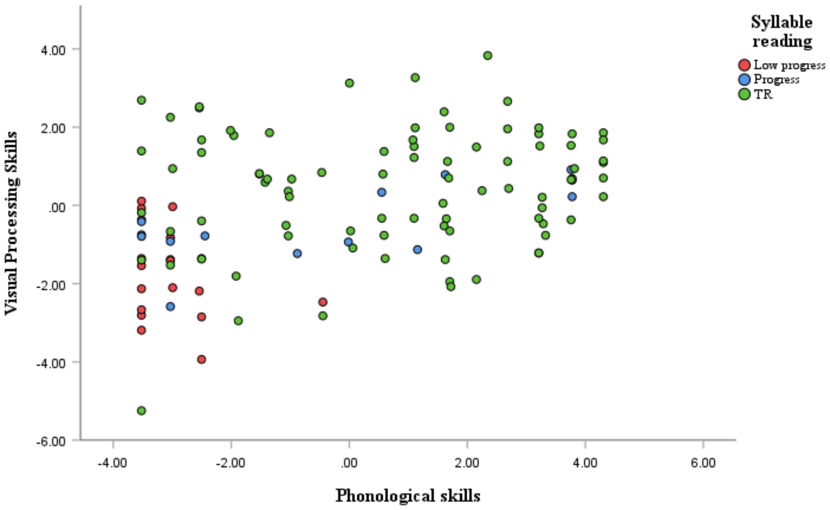


Figure 6. A scatterplot of the relationship between phonological and visual processing skills on the entire sample (N=119).

To evaluate the double deficit hypothesis, phonological skills and visual processing efficiency were converted from continuous variables to binary variables, using the cut-off values identified in Study 2a: - .92 for phonological skills (composite score) and -.42 for visual processing efficiency (composite score).

Results

The comparative analysis indicates that the two groups of children at-risk were equivalent regarding phonological memory skills and lexical access skills. However, all other variables were significantly different in the two high-risk groups, suggesting somewhat different cognitive profiles of those children who could catch up with the reading skills respect of those who rested poor readers at the end of the second grade.

The two groups of children at risk, and both of them are compared with the group of typically developing readers. It could be noticed that the two groups at risk for dyslexia obtained lower scores not only for the reading tasks but also for the predictor variables were significantly lower. The children from the progress group, even if they catch up and overcome the reading deficit, will remain fragile and need more attention from the teachers because they have generally lower profile respect for the typically developing readers' group. Inside the two at-risk dyslexia groups of children, we analysed the association between predictors and the reading score. In the correlation analysis, variables that contributed to the variations in the reader profiles were introduced. Table 10 presents the correlation data. Both phonological skills and visual processing efficiency scores were moderately correlated to the text reading scores. The initial sample of participants in this study was not selected; however, all the children in their class were included. The study reveals the relationship between non-verbal intellectual abilities and learning outcomes. Our data suggest that inside the at-risk group of children, cognitive abilities are related to the level of reading acquisition and, implicitly, with progress.

Table 10

Correlations Between Predictors and Text Reading Scores

Variable	**2**	**3**	**4**
1. Text reading	.498**	.437*	.575**
2. Phonological awareness (composite)	-	.450**	.472**
3.Visual processing (composite)		-	.380*
4.IQ (Raven)			-

*p=.05, **p=.01, ***p=.001

These data support the hypothesis of the influence of these variables on the progress of reading acquisition, as the predictors ‘ data was collected before the onset of literacy training (*Hypothesis 4*).

Another question, with clinical practice implication, regards the possibility of early detection of those children who will make no progress with the aid of school-based reading training. A visual inspection of the scatter plot suggests that an association between phonological and visual attention low scores characterises the low progress group. When the two predictors were converted to categorical variables, we found that 13 out of 18 members of the low progress group obtained low scores on both predictors, while only 2 out of the 14 members of the progress group had a double deficit. The results of Fisher's Exact Test ($p<.001$) indicate a significant association between the presence of a double deficit (in the language and visual skills) and low progress in reading acquisition (*Hypothesis 3*).

Discussion

This study analysed a sample of children with a high risk for poor reading skills identified with a screening test after one year of compulsory literacy training. Some children initially included in the high-risk group could recuperate the gap and showed age-appropriate reading skills at the end of the second grade. We hypothesised that several cognitive characteristics could be promotive factors preventing some children from becoming dyslexic (Slomowitz et al., 2021). We further analysed the group differences to understand the main differences between the two groups: those with a low achievement rate and those with a typical performance. Analysis of their cognitive profile showed that the two groups of children at risk for dyslexia were equivalent in terms of processing speed, lexical access, and phonological memory skills. However, significant differences were found, between the two groups, in terms of non-verbal cognitive skills, visual processing efficiency (especially visual-spatial attention orienting) and phonological skills. Of clinical interest is the low progress group cognitive profile. We performed a case-by-case analysis to individuate the main factors associated with low achievement. When the -.92 cut-off for phonological skills and the -.42 cut-off for visual processing skills were applied, 72% of the low achievers were correctly identified. Fisher's

Exact Test indicated that a significant proportion of the children of the low progress group had a double deficit, covering not only language skills (phonological awareness), as most of the precedent research has demonstrated, but also the visual-attention processing deficit. We found that the association of a phonological deficit with a visual processing deficit could be the marker of those children who will develop severe dyslexia; the 'severe' means there is resistance to the educational training process. This data supports the study's results on the entire sample of 119 children, as the visual processing skills uniquely explained the reading level.

Study 3- Testing the Differences Between the Cognitive Profiles of Good and Poor Readers in Two Samples of Second Graders

The early view of development considered it appropriate to study different age levels as independent between them. Neuroconstructivism changed the previous paradigm, assuming that research on developmental disorders has to understand and interpret the changes that occur from one stage of development to another, considering that the behaviour-generating cognitive architecture is determined by two categories of factors: intrinsic factors and the environmental interaction (Westermann et al., 2007). These transformations refer to the reading acquisition and the evolution of the cognitive functions associated with reading acquisition. Some of these changes are due to maturation, while the reading experience determines others. Thus, it is generally accepted the assumption that the development of phonological skills is influenced by learning the alphabetic principle during the early stages of literacy acquisition (Zoccolotti, 2022). Similarly, a maturation of the visual processing skills is supposed to occur during reading acquisition, as the repeated experience with a cluttered visual field like the written text could determine. This is why collecting data on reading skills and the associated variables could offer a comprehensive and detailed map of the cognitive development of typical readers and children with dyslexia. Evidence on the cognitive profiles of poor readers showed that various predictors account for the variations in reading skills, not only when these variables were measured before literacy acquisition but also later. Many studies analysed the differences in language skills associated with reading level (see (Melby-Lervåg et al., 2012; Snowling & Melby-Lervåg, 2016). Lexical access based on a verbal fluency task was also shown to vary in relation to the reading level (Baldo et al., 2006; M. J. Cohen et al., 1999; Smith-Spark et al., 2017), as well as visual attention skills (M. Bosse & Valdois, 2009; Franceschini et al., 2012, 2022; Frey & Bosse, 2018).

The results of the previous study showed that different prediction models account for the variations in reading performance on tasks, tapping on the phonological decoding and lexical pathways. We also demonstrated the influence of a low level of prerequisite phonological skills and visual attention-orienting skills on the low achievement profile that could characterise severe dyslexia. This double visual-phonological deficit that describes severe dyslexia could have a role in clinical practice. It could help identify severe dyslexic children even after the onset of reading acquisition.

This study aimed to investigate the stability of the double deficit as a marker of severe dyslexia in second-grade children. We used a correlational study design to model the prediction of dyslexia risk based on hierarchical regression. We used G*Power (Faul et al., 2009) to calculate the minimum sample size necessary for a multiple regression-based statistical analysis. The minimum sample size was N=40. Our hypotheses were:

Hypothesis 1: Visual processing efficiency can uniquely predict the variance in reading level, even when predictors are measured at the same time as reading performance (the second grade).

Hypothesis 2: Lexical access can uniquely predict the reading level, besides other predictors, being more related to the lexical reading stage.

Method

Participants.

The survey involved a group of 32 children with reading difficulties (14 males and 18 females) and a control group of 31 (12 males and 19 females) of similar socio-cultural characteristics (children from 3 schools in Cluj-Napoca, and three schools from a semi-rural environment in the extreme outskirts of Cluj) and an average intellectual level. The two groups were formed based on performance in the passage reading task (bad readers <25°, and good readers >60°). Table 1 shows the characteristics of children regarding age, male/female ratio, and their provenience.

Materials

The predictors and the reading tasks were similar to those described in Study 2.

Results

The two reading groups significantly differed in reading level measures and other variables associated with reading acquisition except for the phonological memory span.. Among the cognitive factors involved in the processing of written text, less significant differences between the two groups were found in phonological memory and categorical fluency, while for all other variables, the two groups present significant differences.

The predicting models for non-word reading in the third year of literacy instruction suggest a similar evolution of the association between reading and literacy predictors in the two reading pathways: sub-lexical and lexical. Visual attention skills significantly predict the reading level for non-word and word tasks, determining the most critical R^2 change. Besides them, lexical access also predicts reading acquisition for both pathways. The contribution of the language skills increases as the task passes from the sub-lexical to lexical decoding strategy.

Table 14

Hierarchical Regression Models for The Second-Grade Nonword Reading Score

Variables	**b (SE)**	**β**	**p**	R^2	ΔR^2
Step1				.210	.210
PA (composite)	.08(.02)	.46	<.000		
Step 2				.312	.102
PA (composite)	.06(.02)	.35	.003		
Visual attention (composite)	.23(.08)	.34	.004		
Step 3				.384	.072
Visual attention (composite)	.16(.08)	.24	.042		
Lexical access (composite score)	.04(.01)	.48	<.000		

*p=.05, **p=.01, ***p=.001

The presence of lexical access as a predictor in the non-word reading model supports reading development as a compact competence during global decoding. The three series of predicting models for non-word, word, and text reading in the second grade support the hypothesis of a significant association between visual attention-orienting deficit and reading acquisition. Its contribution to the prediction model increases while children's approach to the reading task passes from the sub-lexical to global strategies. This result is concordant with the conclusions of the previous studies of this research.

Table 15

Hierarchical Regression Models for The Second-Grade Word Reading Score

Variables	**b (SE)**	**β**	**p**	**R^2**	**Δ R^2**
Step1				.288	.288
PA (composite)	.14(.03)	.53	<.000		
Step 2				.434	.146
PA (composite)	.11(.03)	.41	<.000		
Visual attention (composite)	.40(.10)	.40	<.000		
Step 3				.470	.036
PA (composite)	.08(.03)	.30	.013		
Visual attention (composite)	.32(.10)	.33	.003		
Lexical access (composite score)	.03(.02)	.24	.049		

**p*=.05, ***p*=.01, ****p*=.001

Table 16

Hierarchical Regression Models for The Second-Grade Text Reading Score

Variables	**b (SE)**	**β**	**p**	**R^2**	**Δ R^2**
Step1				.300	.300
PA (composite)	.19(.04)	.55	<.000		
Step 2				.457	.157
PA (composite)	1.48(.04)	.41	<.000		

Visual attention (composite)	.56(.13)	.42	<.000		
Step 3				.504	.047
PA (composite)	.10(.04)	.28	.013		
Visual attention (composite)	.44(.14)	.33	.002		
Lexical access (composite score)	.05(.02)	.28	.021		
Step 4				.513	.009
Visual attention (composite)	.41(.14)	.31	.004		
Lexical access (composite score)	.07(.02)	.40	<.000		
Phonological memory span	.40(.14)	.26	.007		

**p*=.05, ***p*=.01, ****p*=.001

Discussion

The results of this study represent continuity with evidence from the reading development literature that, on one side, showed that there is stability in the cognitive profile of children with developmental dyslexia from the preliteracy stage to the end of the compulsory school-based reading acquisition programme (Ozernov-Palchik et al., 2017). Due to the sample selection (the participants were matched based on age and non-verbal cognitive skills), no differences were found between the good and the poor readers in Raven's coloured matrices scores. This study's poor readers group corresponds to the low progress group of *Study 2b*, as they were identified as poor readers close to the end of compulsory reading training (second grade). This is why an analysis of their cognitive profile could bring additional data on the evolution of the association between the pre-reading predictors and reading and the same variables evaluated simultaneously as the reading measures.

Language skills (phonological awareness and lexical access) contribute to a well-fitted model. Both can contribute to severity analysis when an individual diagnosis is required (*Hypothesis 2*). There is a variation in the phonological abilities' contribution to the prediction model as the dependent variable moves from the phonological decoding pathway to the lexical pathway. This difference could be determined by the insufficient consolidation of the sub-lexical pathway, even in good readers, as other research data on the Romanian population suggest. This result is concordant with the data obtained during the validation study of the DDE-2 (Rosan et al., 2021), when we found an increasing gap between the sub-lexical and lexical skills with age. This means that, with the automation of the decoding processes, the sub-lexical strategies are less practised by children. Moreover, as the children of the low readers' sample were mostly letter-by-letter readers, their reading speed was low even on the non-word reading task.

The association between all the reading task scores and lexical access is relevant as related to more general linguistic difficulties that could impact the learning skills mediated by language. In this view, the lexical access deficit could indicate dyslexia severity, as it could impact learning outcomes in various fields.

All predictor models confirm visual processing efficiency as the primary variable that allows one to uniquely explain the variation in reading skills besides the contribution of phonological awareness (*Hypothesis 1*). This brings additional data that supports the results of the previous studies included in this research, which showed that visual attention skills are a significant predictor of the lexical level of reading. Interestingly, it proved to be a transversal predictor, regardless of the type of reading task involved. A previous study (Gavril, 2016) demonstrated that visual attention skill has an upward trend in all children, regardless of their reading skills. However, the slope of the growth curve is higher in typically developing children than in the case of children with dyslexia. This trend could explain the differences between the predicting role of the attention skills measured before the onset of the literacy training and the same skills evaluated during the third year of literacy training: while in good readers, there is higher progress in the visual attention skills development, in poor readers the increase is less significant. Our results support the conclusions of White et al. (2019), who suggested a delay in the maturation of visual attention skills in children with dyslexia compared with typically developing readers.

The results of this study show that at the second grade, the variations in the predicting models of various reading tasks diminish, the same predictors being involved in the predictive models for all types of reading tasks. The study also confirmed that, when controlling the general cognitive abilities (Raven), visual attention skills and lexical access based on a phonemic cue are the most important predictors of reading besides phonological skills.

Study 4 –Bimodal Intervention: Visual-Attentional and Imposed Time Constraint in Dyslexia. A Pseudo-Randomized Study

Various types of training programmes to improve reading skills in at-risk children or dyslexic children were created based on those that were considered the primary causal cognitive deficits in dyslexia. According to the dominant view of a phonological awareness deficit as the core cause of dyslexia, most intervention programmes included activities to improve phonological skills or phonics training. However, it has been shown that phonological skills intervention is likely inefficient in about 33% of the participants (Whiteley et al., 2007). Evidence shows that interventions based on special education methods often stabilise the reading deficit level rather than normalising reading skills (Gabrieli, 2009).

Another line of dyslexia intervention research is related to the evidence on the visual attention deficit in reading-impaired children. This deficit is associated with the efficiency of visual spatial attention orienting, temporal processing, and attention shifting (Facoetti, Trussardi, et al., 2010; Franceschini, Bertoni et al., 2017; Hari & Renvall, 2001). It has been shown that the temporal processing deficit is not confined to the visual modality but characterises auditory processing (Stein et al., 2009).

Functional neuroimaging studies have shown that the gradients of word selectivity in the occipital-temporal cortex and the inferior frontal cortex and the connectivity between them, characterising typically developing readers (Maurer et al., 2009), are absent in children with dyslexia. Evidence suggests a relationship between brain activation and behavioural data obtained through reading standardised measures (Olulade et al., 2015). Hypoactivation in the VWFA (visual word form area) situated in the occipital-temporal cortex in dyslexic children was confirmed by various studies that examined not only English but also German or Italian-speaking children, and suggest a lack of specialisation in those areas for dyslexic children, indicating a stable pattern of differences between people with dyslexia and typical readers, regardless of the orthographic complexity of the language(Paulesu et al., 2001; Van der Mark et al., 2009). Hypoactivation of the inferior-frontal cortex appears to be related to word retrieval during the naming task and to orthographic serial processing, similar to the mechanisms involved in the global decoding mechanisms (Richlan, 2014). This area was found to be hypoactive concerning the processing of written words processing (Olulade et al., 2015). As all these areas are activated during written word processing, they are supposed to be interconnected. However, in dyslexic children, these connections are weaker than those found in typical readers (Olulade et al., 2015). Those connections are supposed to be built during reading acquisition, resulting from repeated activations of the areas that need to be simultaneously activated. If any of the two target areas (the visual or the language ones) is not activated (visual or phonological deficit), this would probably prevent the interconnection building. An intervention programme to facilitate reading acquisition should stimulate visual and verbal aspects to facilitate their interconnection building. These functional data suggest that to be efficient, an intervention should work on both aspects to promote both language and visual skills, as this could strengthen connections between the regions concerned.

Different types of intervention programmes were built to improve visual processing efficiency. *Reading acceleration programmes* were based on visually briefly presented letter strings, and the child's task was to recognise them. This type of task included the visual-phonological conversion of the stimuli, so phonological skills were also involved (Franceschini, Trevisan, et al., 2017; Lorusso et al., 2006). Visual perceptual training programmes were based on developing the visual pathway of written word information transmission (Lawton, 2016; Lawton & Shelley-Tremblay, 2017). Other remedial programmes imposed a fixation point and manipulated the saccade's length, improving accuracy in impaired readers (Werth, 2018). Action video games have been shown to improve reading fluency by training visual-spatial attention orienting and decreasing the time to response (Bertoni et al., 2021; Franceschini et al., 2013, 2015; Franceschini, Trevisan et al., 2017; Franceschini & Bertoni, 2019).

Here, we report a feasibility study proposed in the programmatic guidelines for evaluating cognitive training programmes by Green et al. (Green, S. et al., 2019).

This study aimed to test the feasibility of a dual-mode intervention for dyslexia, including the early data on the efficacy of this treatment. The study was a pseudo-experiment, as the parent's decision determined inclusion in the experimental or control group. Analysis of variance based on a repeated measure two-group design was used to evaluate the effects of the training program. We hypothesised that an intervention program that combines visual attention and working memory tasks with sub-lexical reading tasks with imposed time constraints would determine an improvement in reading skills superior to the changes in decoding skills determined by maturation (control group). We used G*Power (Faul et al., 2009) to calculate the minimum sample size necessary to analyse variance. Considering the lowest $\eta 2=0.4$, the minimum sample size is N=24.

Method

Participants

Ten sample children (M/F = 4/6) were diagnosed with developmental dyslexia (mean age=9.91 years, SD=1.16 years, range = 8.08 – 11.91, mean full IQ= 115, SD= 13); the diagnosis of dyslexia was based on a complete assessment procedure that included: average full IQ (≥85), and reading evaluation. All the children had normal or corrected-to-normal vision, no other neurological disorder, and reading scores (errors or speed) at least 2SDs below the norm on at least two of the three-word, non-word or text reading tasks. The progress of this sample was compared with that of a control group including 12 chronologically matched children (M/F = 6/6) diagnosed with developmental dyslexia (mean age=10.33 years, SD=1.08 years, range = 8.58 – 13.75, mean complete IQ= 116, SD= 10). Participants were not randomly assigned to a group, but their participation in the programme was based on their family's decision to participate in a remedial programme for dyslexic children.

Results

The analysis of variance with repeated measures was used to analyse the differences between the Pre-test and the Post-test in the intervention and the control group. The between-subjects variable was Intervention Vs. Control Group, while the within-subjects variable was the reading score (pre-test Vs post-test).

A preliminary analysis indicated that the two groups were similar in the pre-test, as the variances were insignificant. In the post-test, the scores of the two groups were significantly different. A one-way analysis of variance for repeated measures was performed. This would permit avoidance of overestimating the effect size of the change in the reading speed as a consequence of the intervention delivered.

Table 17

Means and Standard Deviations for the dependent variable

Variable	Intervention group		Control group			
	M	SD	M	SD	F (1, 20)	η2
Pre-test (z-scored)	-1.68	.54	-1.61	.48	-.59 (n.s.)	-.25
Post-test (z-scored)	-1.27	.70	-1.78	.31	1.94*	.84

**p*=.05, ***p*=.01, ****p*=.001

Table 18

One-way Analysis of Variance for Effects of the Training Program on the Dependent Variable

Source	df	SS	MS	F	η2
WR (Pre-test - Post-test)	1	0.14	0.14	3.71	.16
Group	1	0.50	0.50	1.02	.05
WR x Group	1	0.91	0.91	23.48***	.54
Residual	20	.77	.04		

**p*=.05, ***p*=.01, ****p*=.001

WR = word reading speed (z-scored)

The group's main effect was insignificant F (1, 20) =1.02, p=.33, indicating that the two groups were equivalent regarding the reading deficit. The contrasts between the pre-test and the post-test did not show significant differences F (1, 20) =.12, p=.738. The interaction between the group and the reading speed change was significant: F(1, 20) = 23.48, *p*=<.001, partial η2=.54.

The observed power was .99. This indicates that the differences between the post-test and the pre-test were significantly different in the two groups (Figure 8), supporting the hypothesis of a significant effect of the training program in the intervention group, while the reading speed of the control group did not increase significantly. It can be noticed that the effect size is re-dimensioned with the use of ANOVA, while it remains large ($\eta 2>.40$) and significant. The results indicate that the gap between the reading scores of the experimental group and the mean is decreasing. For the children of the control group, the increase in the reading rate due to maturation processes was insufficient to fill the gap that divided them from the expected results.

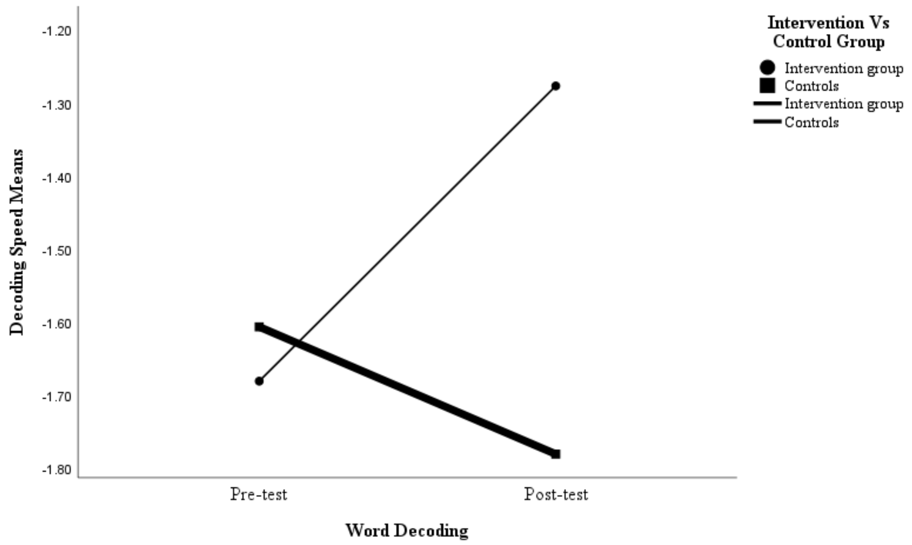


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Figure 8. Pre-test and post-test word reading levels in the two groups

Discussion

This study reports the pilot test results for a bimodal intervention in dyslexia. Evidence shows that children with dyslexia with a double deficit, visual and phonological, are susceptible to insufficient gain from educational intervention for reading acquisition (Wanzek et al., 2013).

At the same time, neuroimaging data suggest an inadequate activation of the visual and language cerebral areas in children with dyslexia. The interconnection between these areas is also weaker in persons with dyslexia compared to typical readers. This atypical functioning data suggests that any intervention that taps only one of the two components could not be able to increase the functional connections between visual and language skills. A previous meta-analysis showed that unimodal interventions for dyslexia remediation produced results with modest effect sizes, ranging from 0.07 to 0.56 (see Wanzek & Vaughn, 2007; Wanzek et al., 2013).

The apparent regress of the control group was not due to lower performance in the post-test compared to the pre-test. On the contrary, there was a natural increment in the reading speed even for the group that did not receive any intervention. However, the increment of the reading proficiency of children with dyslexia is usually lower than that of typically developing children. Even for the control group, the effect of maturation is present. However, their gain is 'masked' when their scores are referred to their age norms. This finding is consistent with evidence from previous research (e.g., Suggate, 2010).

This large effect was obtained by modest but consistent gains in reading fluency after seven months of varied activities, twice a weekly programme, based on visual attentional visual memory training on one side and the imposed time constraint on the other.

Data obtained by monitoring the participants in this bimodal training programme are encouraging, as the reading skills outcome was significantly improved after the intervention. However, no data was collected regarding visual and phonological skills.

As a feasibility study (see Green et al., 2019), this research aimed to identify the potential problems that could occur during implementing such an intervention program. It was able to estimate the effect size and test the effect size of the effect for bimodal intervention. One problem identified was the relative lack of motivation associated with the word recognition component of the program. This task was effort-demanding, and besides the clinician's intervention, no intrinsic motivators were included (like a token system). This task was too difficult and unpleasant for most children, so they avoided it. However, it was suggested to the children and their parents to continue to practice even outside the intervention hours.

As a pilot study, we did not aim to investigate the mechanisms of action for this dual program of cognitive enhancement. A future study should realise a complete assessment of the visual and phonological skills before and after the training. This would permit the generation of a theoretical explanation of the observed changes in reading performance based on this approach. Randomly allocated participants to the two groups would be needed, and all the confounding variables should be rigorously controlled.

Another aspect to consider is the necessity to evaluate de efficacy of this dual intervention compared to other interventions. To date, a significant number of studies investigated the efficacy of phonological training programs. During the last ten years, a series of studies demonstrated that interventions oriented to visual attention enhancement could also determine an increase in reading speed, which results in being the feature that is less susceptible to improvement.

An effectiveness study to analyse the potential differences between various intensities of the training sessions (e.g., once-a-week training sessions), in terms of variations of the gains for the trained children, should also be investigated.

All these data would significantly impact the clinical practice, allowing the clinician to estimate the opportunity to implement an intervention considering each child's reading level and the potential improvement that could be obtained. This is necessary to offer the family precious information regarding times and costs related to a specific gain. The evidence suggests no age limit to implementing an intervention program for reading rehabilitation. However, after the fourth year of elementary school, it is difficult to recommend an intervention for reading speed improvement because the school requirements are so high that no reading training can determine an *evolution* to independent study. Children who enter secondary school with a severe reading impairment must be assisted in their home-based study. This is why a large enough corpus of data to indicate the possible evolution through a training programme would be utile by clinicians to choose between recommendations towards intervention or assistive intervention/technology to support children with dyslexia.

Chapter IV – Conclusions and *General discussion*. This chapter highlights the research results and several considerations regarding its usefulness both from a theoretical perspective and from the point of view of clinical practice, answering questions about identifying severe dyslexia.

This first study has highlighted the association between visual attention and reading acquisition. It distinguishes between studies that used serial visual processing of complex stimuli from parallel processing visual tasks. The variations in the strength of the association between the two variables throughout the reading acquisition period were also considered.

The results confirm that the gap in visual attention skills between typical readers and people with dyslexia evolves, from moderate to high, from pre-literacy to mature reading. It has also demonstrated the importance of orthographic depth in the relationship between reading and attentional processes.

The method of teaching (based on phonetics learning Vs global decoding) could be a determinant for the visual approach of the written words, and this variable was not included as a moderator in our meta-analyses. Children are sometimes taught to recognise words globally, even when the language has a shallow orthography. Further research on how visual-spatial attention skills evolve during reading acquisition would be helpful when designing effective teaching methods and developing approaches for diagnosing and treating children with reading disorders (Gavril et al., 2021).

The second and the third study analysed the predicting role of various prerequisites of reading acquisition. The results suggest that different decoding pathways are associated with different patterns of predictors. While, in the pre-literacy study the sub-lexical decoding had only language-based predictors (related to phonological awareness), the lexical decoding demonstrated similar predicting patterns, whether we used word recognition tasks or text reading. This could be interpreted as a consequence of specific processes involved in each decoding task. For the lexical decoding, more predictors contributed to explaining the variations in the reading level. The sensitivity and specificity of these models improved compared to the models predicting early decoding skills (non-word reading).

The second study also investigated the role of visual attention processing in prediction models for various reading outcomes, bringing additional evidence to the role of visual processing efficiency in reading acquisition. It also brings additional data to the prediction of reading disorders based on an unselected population-based sample, as most of the existing evidence was based on samples of children from a family risk of dyslexia. Using a non-selected sample improves the possibility of generalising the results to the entire population. Data emerging from this study support the role of visual processing skills in predicting reading level, especially for the lexical stage of reading development. Our findings extend the work of (Thompson et al., 2015), as, on the one hand, analysis of the prediction of dyslexia on an unselected sample, on the other hand, introduces visual skills as a separate predictor in the model. The study examined which factors may affect the early acquisition of reading speed in Romanian children, focussing on non-word reading, an ability that seems directly affected by the nature of the language phonology, as an early measure of reading development, and on non-word, word and text reading at the end of the compulsory reading training (second grade). Between the many possible predictors of reading acquisition, the present study focused on three types, i.e., phonological awareness, visual analysis efficiency, and retrieval efficiency from long-term memory based on phonemic cues. As the level of development of these cognitive functions can have different consequences in various stages of decoding ability, our study tried to disentangle their influence on early phonological decoding from the influence on the later change in reading ability.

The results showed the importance of phonological awareness and visual analysis efficiency for early phonological decoding. The importance of phonological competence for literacy acquisition is largely accepted (Melby-Lervåg, 2012; Vellutino, Fletcher, Snowling, & Scanlon, 2004). However, it has also been suggested that the interventions focused on developing phonological abilities do not improve decoding speed if these interventions are carried out after poor reading was acknowledged (see Bus & Van IJzendoorn, 1999). This suggests that an improvement in phonological abilities is not related to the change in reading acquisition after the learning process was initiated, consistent with our results showing that the role of phonology relates to the early phonological decoding but has no influence on the later change in reading acquisition.

The importance of visual attention as a causal factor in reading disabilities is still under debate (Goswami, 2015). However, a growing corpus of research shows the relationship between visual processing and reading performance. This relationship was mainly investigated for a transparent language like Italian (e.g., Facoetti et al., 2010), particularly in early reading experiences. Our data suggest that the visual analysis efficiency, as a composite factor measured by a visual search task using non-letter material and a visual processing speed test also using non-verbal material (WISC-IV Symbol Search), is related predominantly to the lexical level of decoding. These findings support the conclusion of Study 1, which showed that the association between visual attention skills is stronger in mature readers compared to beginner readers (Gavril et al., 2021).

The following model summarises the conclusions of the studies included in this research. According to our data, the first stage of reading acquisition is supported by phonological skills. However, during the automation of reading the passage to global word recognition, visual skills and lexical access have a crucial influence on the level of reading skills acquisition. The results of this study support the multiple deficit model (MDM) proposed by Pennington since various deficits were found to be associated with low reading performance, alone or in combination (McGrath et al., 2020; Pennington et al., 2012).

It confirmed previous evidence in the case of a language that had not been studied before but also offered new suggestions. The results also have practical implications. For example, as phonological and visual abilities are crucial during the first steps of reading acquisition, specific training could be included in the formative programmes of kindergartens as preparation for elementary school. This finding would apply to Romanian schools and probably other countries speaking neo-Latin languages. Testing modalities to improve the intervention is necessary to identify how to train one function that contributes to the reading development and train two functions simultaneously to determine an increased connection between them.

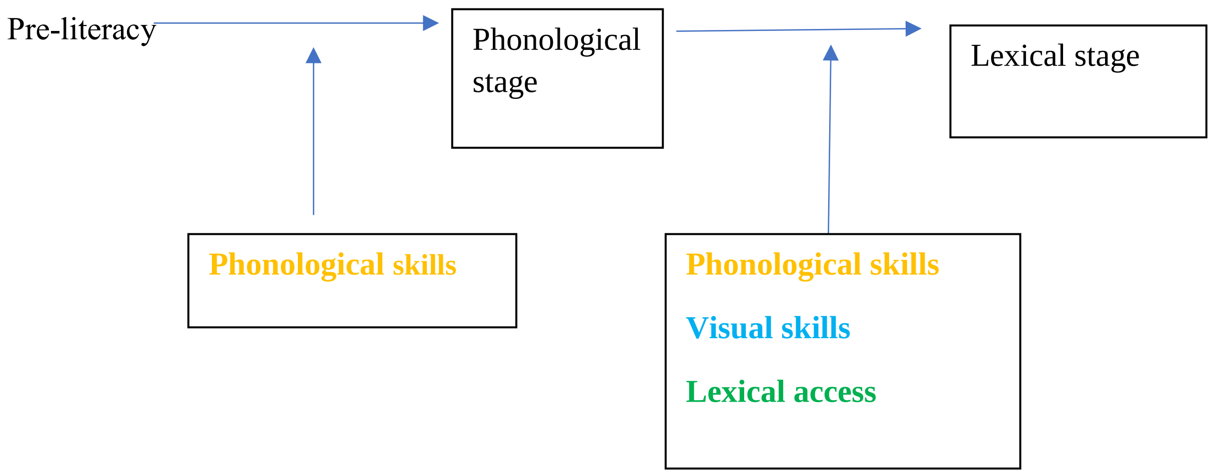

Figure 9. Model of predicting variables along the reading development

Existing evidence suggests limited possibilities to improve reading by training one cognitive skill associated with low reading skills acquisition. Most of the existing literature on intervention in dyslexia was oriented toward phonological skills training, as it was considered the core causal factor of dyslexia. As recent data sustained a contribution of the visual attention skills impairment in the reading deficit, several intervention programs were tested to sustain reading development.

This research project is the first to test a bimodal intervention aiming to stimulate language and visual skills concomitantly to enhance the association between the two cognitive processes. The study presented here is a pilot study that provides promising results. However, the data presented in this research should be extended to explain the observed results mechanistically. A randomised controlled clinical trial is also necessary to estimate the magnitude of the improvement that can be expected and the consequences on the effectiveness of the variations in the intensity of the programme delivered. The importance of an integrated reward system to motivate the children to practice the exercises proposed, despite the effort needed, was acknowledged.

Future research to determine the magnitude of the expected effect would help clinicians by permitting them to estimate the results and to decide on recommending intervention or assistive technology.

Limitations and Future Direction

A limitation of the pre-literacy prediction study was the small number of participants in the initial sample, which did not permit the identification of a large enough sample of at-risk children. The results should be confirmed by other research that could include a larger sample to obtain robust results in the risk group analysis. Another limitation was the lack of a visual attention span task to evaluate the contribution of other aspects of visual processing features. A future study should extend the composition of the visual attention tasks by including a visual span task and a temporal order judgment task, as these features of visual processing were also found to be related to reading impairment in previous research. However, the present results offer crucial new evidence in early reading acquisition. The research results were coherent: all the studies concorded with the importance of considering visual processing and lexical access as significant predictors in screening programmes. However, the low number of at-risk children makes it difficult to formulate robust conclusions. A future study with a larger sample could bring additional evidence to the model of predictors' role during the reading development phases.

The visual processes included in the prediction models were confined to visual-spatial attention orienting. The results of this study should be extended by adding one more visual task (a visual attention span task, a visual, serial attention and memory task) and a rapid automatised naming task. By introducing these tasks, it could be possible to introduce an additional measure, the serial-multi-stimuli processing speed and to disentangle its contribution from that of the visual search task. The evolution of the at-risk group should be monitored for a more extended period to describe development curves for each of the deficits identified.

Although the intervention study included in this research followed the requisites of a feasibility study, it should be continued with an efficiency study that should evaluate the changes in all the variables involved: visual attention skills, phonological skills, and reading skills (on both pathways).

Dissemination of Research contained in the thesis

Publications:

1. David, Roșan, Gavril (2018). Reading Strategies of Romanian Readers with Dyslexia in Upper Primary Grades, *Prima Educazione.* DOI: 10.17951/pe/2018.2.89-98.

2. Gavril, L. (2019). Dislexia: Simptome, cauze, intervenție. Cluj-Napoca: *Sinapsis Publishing Projects.*

3. Gavril, L., Roșan, A., & Szamosközi, Ștefan. (2021). The role of visual-spatial attention in reading development: A meta-analysis. *Cognitive Neuropsychology*, *38*(6), 387–407. https://doi.org/10.1080/02643294.2022.2043839.

Participation in validation studies for:

4**.** Sartori, Job, Tressoldi (2013). Bateria pentru evaluarea dislexiei și a disortografiei de dezvoltare – 2 (DDE-2); trad. și adapt. Roșan Adrian Marian (coord.), Gavril Lorana-Corina, David Carmen Viorica, Vălesăsan Adela, Bălaș-Baconschi Cristina – București: *O.S. Organizzazioni Speciali România*, 2021.

4. Cornoldi & Colpo (2012). Probe de lectură MT-2 pentru școala primară; trad. și adapt. Roșan Adrian Marian (coord.), Gavril Lorana-Corina, David Carmen Viorica, Vălesăsan Adela, Bălaș-Baconschi Cristina – București: *O.S. Organizzazioni Speciali România*, 2021.

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2021 Conferința Asociației Naționale a Psihologilor-participare cu lucrarea: „Procesarea vizuo-spațială în dezvoltarea citirii”

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