



HAL
open science

Validation of a screening test based on symbols visual search to detect visuo-attentionnal reading difficulties

Audrey Vialatte, Eric Chabanat, Agnes Witko, Laure Pisella

► To cite this version:

Audrey Vialatte, Eric Chabanat, Agnes Witko, Laure Pisella. Validation of a screening test based on symbols visual search to detect visuo-attentionnal reading difficulties. *Research in Developmental Disabilities*, 2025, 156, pp.104897. 10.1016/j.ridd.2024.104897. hal-04863048

HAL Id: hal-04863048

<https://hal.science/hal-04863048v1>

Submitted on 3 Jan 2025

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Research in Developmental Disabilities

Volume 156, January 2025, 104897



Validation of a screening test based on symbols visual search to detect visuo-attentional reading difficulties

Author links open overlay panel Audrey Vialatte ^a, Eric Chabanat ^{a b}, Agnes Witko ^{b c}, Laure Pisella ^a

<https://doi.org/10.1016/j.ridd.2024.104897>

Highlights

- Written symbols are specific stimuli made up of a spatial combination of strokes.
- Our temporal gap index contrasted visual search of symbol versus colour.
- Reading speed and accuracy significantly correlated to visual search index.
- Individual centile categorisation did not differ between visual search and reading.
- Our visual search screening test obtained 63 % sensitivity and 71 % specificity.

Abstract

Objective

Visuo-attentional dyslexia has been associated with impaired simultaneous visual processing of multiple items made of separable features (i.e. symbols). We designed a visual search screening test, consisting to find the (unique) black circle among circles of various colours versus among circles combined with a bar of various length and location. We evaluated its reliability and its validity to detect visuo-attentional deficit prone to affect reading.

Results of study 1

Assessment of 2015 children between 3 and 11 years old established that the screening test was feasible from kindergarten, and that our index contrasting visual search performance for symbols relative to colours (the Temporal Gap) decreased with age. Satisfactory test–retest reliability of the standardised index (independent from age) was found on a sample of 69 individuals.

Results of study 2

Reading speed and inaccuracy assessed for 769 4th and 5th grades children were significantly correlated to the Temporal Gap. A Temporal Gap above 75th centile predicted reading efficiency deficit above 95th percentile with 63 % sensitivity and 71 % specificity.

Perspectives

Our screening test can be used in clinic to detect whether a child with developmental dyslexia presents visuo-attentional fragility prone to contribute to the reading difficulties. Its validity as early predictor of a risk to develop visuo-attentional dyslexia needs further investigation.

Keywords

Simultaneous visual processing
Reading
Sensitivity
Specificity
Validity
Reliability
Normalisation

What this paper adds?

We designed a visual search screening test to compute the temporal gap between a condition where a black circle has to be found among symbols (circles combined with a bar of various length and location) and a condition where it appears among circles of various colours. This index aimed at quantifying a specific visuo-attentional disability to process visual stimuli characteristic of written language, i.e. symbols defined as shapes made by separable strokes. The visual search screening test was easily performed by 2015 children aged from 3 to 11. The standardised temporal gap showed a satisfactory test-retest reliability across ages. In 769 children of 4th and 5th grades, it predicted 5.3 % of the variance of reading efficiency. The

centile categorisation of performance in the visual search screening test and in the Alouette reading test were not statistically different, whether reading speed or inaccuracy was considered. Visual search index above the 75th percentile allowed us to detect reading efficiency deficit (above 95th percentile) with 63 % sensitivity and 71 % specificity. The lower sensitivity was expected, with false negative individuals corresponding to children with developmental dyslexia solely due to phonological deficits. We conclude that the visual search screening test makes a useful clinical tool to detect whether a child with developmental dyslexia presents visuo-attentional fragility prone to contribute to the reading difficulties. As it was feasible as early as 3 years old it could potentially also constitute an early predictor of a risk of visuo-attentional developmental dyslexia.

1. Introduction

1.1. General context of the present investigation

Developmental dyslexia (DD) is a failure to acquire efficient reading despite normal intelligence and adequate education ([Rutter & Yule, 1975](#)). The most common and sometimes the only causal deficit admitted in DD is the phonological deficit ([Hulme, 1987](#), [Goswami, 2015](#)). However, researches have shown that visual-attentional (VA) deficits are present in several individuals with DD, sometimes in the absence of phonological deficits ([Lobier et al., 2012](#), [Saksida et al., 2016](#), [Valdois et al., 2011](#), [Zoubrinetzky et al., 2014](#)). These non-phonological deficits have been characterized as a difficulty in processing multiple alphabetic or non-alphabetic visual symbols in parallel related to superior parietal lobule (SPL) dysfunction ([Liu et al., 2022](#), [Lobier et al., 2012](#), [Lobier et al., 2014](#); [Lobier & Valdois, 2015](#); [Peyrin et al., 2011](#); [Reilhac et al., 2013](#); [Valdois et al., 2019a](#); [Valdois et al., 2021](#), [Vialatte et al., 2023a](#)). Their clinical measure (the VA span assessment) is only available for children of primary school age, as it involves the verbal report of a sequence of letters or digits briefly flashed on a computer screen to reveal a reduced number of graphic symbols that the child can simultaneously identify in one ocular fixation ([Lobier & Valdois, 2015](#); [Valdois et al., 2003](#)). Hence, VA processing impairment prone to affect the reading acquisition are often discovered later than phonological impairment. A predictor that would detect, as early as 3 or 4 years old, VA difficulties prone to hinder the reading acquisition, would be useful. Indeed, such predictor could provide enough time to clinicians or teachers for initiating a specific intensive VA training program to develop the visual prerequisites for reading acquisition before the first grade.

1.2. Rationale for the choice of symbol visual search as VA predictor of reading

Several visual disabilities that have been evidenced in DD and could be evaluated in Kindergarten exist: a bias toward local level processing rather than global processing of hierarchical symbols ([Bedoin, 2017](#), [Franceschini et al., 2017](#)), poor perceptual visuo-spatial ([Bellocchi et al., 2017](#), [Pisella et al., 2021](#)) and visuo-motor ([Bellocchi et al., 2017](#), [Iversen et al., 2005](#), [Nicolson and Fawcett, 1994](#); [Velay et al., 2002](#); [Vernet et al., 2022](#)) skills, and slow symbol search ([Castles and Coltheart, 1993](#), [Marendaz et al., 1996](#)).

We considered that symbol visual search is a relevant candidate for such early detection since it appeared to be an easy task, feasible as early as 3 years old. It also appeared potentially sensitive because it involves all visual abilities, listed above, shown to be impaired in DD: simultaneous processing ([Lobier et al., 2014](#), [Peyrin et al., 2011](#), [Peyrin et al., 2012](#), [Vialatte](#)

[et al., 2023a](#)) and visuo-spatial perceptual discrimination of symbol ([Bellocchi et al., 2017](#), [Franceschini et al., 2012](#), [Marendaz et al., 1996](#), [Pisella et al., 2021](#), [Vialatte et al., 2023a](#)), overt ([Vernet et al., 2022](#)) and covert ([Facoetti et al., 2010](#), [Franceschini et al., 2012](#)) attentional orienting, and processing at both local and global scales ([Franceschini et al., 2017](#)).

1.3. Rationale for the temporal gap measure

Symbol visual search also appeared specific. More precisely, [Casco and Prunetti \(1996\)](#) have shown that poor readers were slow only in visual search conditions involving symbols, i.e. multi-featured shapes made of the spatial integration of multiple strokes (separable features). Poor readers were not slower than good readers in visual searches involving objects distinguished from distractors by colour, orientation or shape, nor in more complex searches involving a conjunction of these object features. A single tilted bar was also found as quickly as controls among single vertical bars. However, search time was lengthened in poor readers when this tilted bar was combined with other bars to form a single target symbol (K or similar non-alphabetic symbol with a tilted bar) among a set of identical distractors (F or similar non-alphabetic symbols without a tilted bar). Based on this result, we hypothesized that a large *temporal gap* between the search behaviour for a target distinguished by a colour (preserved in poor readers) compared to a target distinguished by a lacking element in a symbol (slow in poor readers) may be specific of a poor reading performance. This temporal gap measure would potentially disentangle VA components that have been related to simultaneous visual processing deficit and SPL dysfunction, from fluctuations of more general attention or executive deficits.

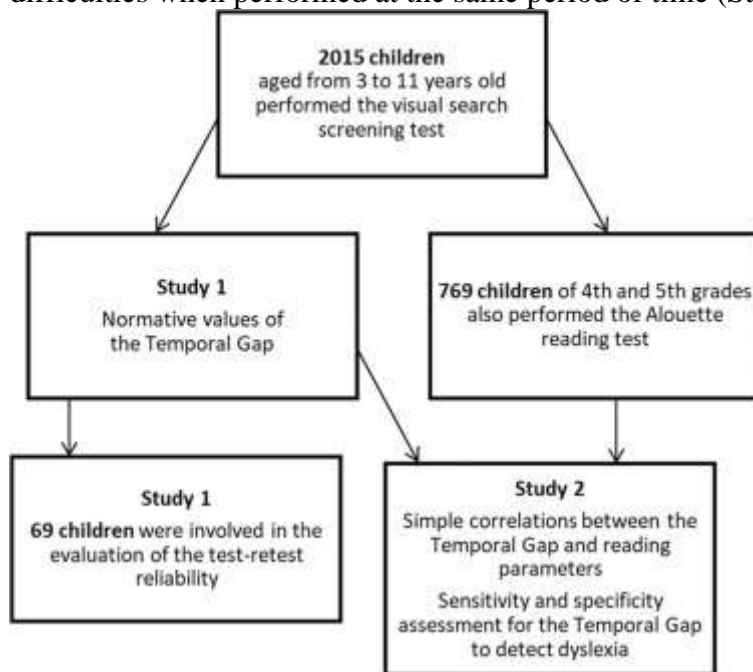
Moreover, a similar dissociation (slow visual search performance for symbols but not for plain or coloured objects) has been observed in a patient with bilateral SPL lesion and impaired simultaneous visual processing ([Khan et al., 2016](#), [Valdois et al., 2019a](#), [Vialatte et al., 2021a](#), [Vialatte et al., 2021b](#), [Wolpert, 1924](#)). This common neural substrate for symbols visual search ([Khan et al., 2016](#), [Vialatte et al., 2021a](#), [Vialatte et al., 2021b](#)) and non-phonological underlying components of dyslexia ([Kevan and Pammer, 2009](#), [Liu et al., 2022](#), [Lobier et al., 2012](#), [Lobier et al., 2014](#), [Lobier and Valdois, 2015](#), [Muneaux and Ducrot, 2014](#), [Peyrin et al., 2011](#), [Pisella et al., 2021](#), [Reilhac et al., 2013](#), [Valdois et al., 2019a](#), [Valdois et al., 2021](#), [Vidyasagar and Pammer, 2010](#)) reinforced our expectation that symbols visual search performance could be used as a valid and reliable screening measure of VA dysfunction potentially hindering reading acquisition.

We therefore designed the visual search screening test contrasting colour versus symbols search performance, and measured the temporal gap between these two conditions. The participant was instructed to find and touch as fast as possible the (unique) black circle. In half of the trials, the black circle target was presented among circles of various colours (colour search task), and in the other half, it was presented among black circles combined with a bar of various length and location (symbol search task). Colour and symbol search trials were randomly intermingled.

1.4. Objective of the present investigation

The scientific validation of such predictor would require to measure pre-reading visual ability in the first years of kindergarten and wait until the same children arrive in 4th grade to evaluate their reading abilities. Indeed, such a longitudinal study would validate the visual predictor for detecting durable difficulties in reading acquisition rather than a delay in the first grade that may be transient; the literature shows that “learning to read” evolution reaches a plateau at the 4th grade ([Aghababian and Nazir, 2000](#), [Chall, 1983](#), [LaBerge and Samuels,](#)

1974). The present article does not report such predictive data yet. It reports the first step of the Ludisymboles research project (Fig. 1) assessing feasibility and reliability of the visual search screening test (Study 1) and its validity to predict the presence of VA reading difficulties when performed at the same period of time (Study 2, Table 1).



1. [Download: Download high-res image \(159KB\)](#)
2. [Download: Download full-size image](#)

Fig. 1. Illustration of the different studies of the Ludisymboles project conducted in French public schools of the Gex region. Study 1 corresponds to the assessment of the feasibility, the normative values and reliability of the visual search screening test Temporal Gap measure. Study 2 corresponds to the assessment of the validity of the visual search screening test to predict reading performance and detect dyslexia in 4th and 5th grades children.

Table 1. Number of participants recruited for both the visual search screening test and the Alouette reading test, and grade at which they received these two tests.

Empty Cell	N total	N females	N males
Visual search at 3rd grade and reading at 4th grade	250	126	124
Visual search at 4th grade and reading at 4th grade	239	119	120
Visual search at 4th grade and reading at 5th grade	63	28	35
Visual search at 5th grade and reading at 5th grade	217	113	104
Total number of participants	769	386	383

1.4.1. First study: normalization and reliability of the visual search screening test

With the idea of a future potential use of the visual search screening test as an early predictor, we wanted to evaluate its feasibility from 3 years old, the evolution with age of the temporal gap between colour and symbol visual search performance, and the test-retest reliability of this index. The normalization of the developmental trajectory of the temporal gap involved a sample of 2015 children aged from 3 to 11 years old and provided the limit allowing the

screening test to determine those children performing fragile or outliers at any age. The test–retest reliability over time of the standardised index (independent from age) was examined on a sample of 69 individuals of various ages.

1.4.2. Second study: relationship between the visual search screening test and reading performance

We aimed at establishing whether the temporal gap between colour and symbol visual search performance was related to reading ability in the sub-sample of 769 children aged between 8 and 10 who also performed the Alouette reading test ([Lefavrais, 1967](#)). We also evaluated how the visual search screening test was sensitive and specific to detect reading deficit assessed by the Alouette reading test. We provided its validity to predict reading performance, and the threshold at which sensitivity and specificity was satisfactory, when visual search and reading were evaluated at the same period of time (4th and 5th grades).

2. Methods

2.1. Recruitment

All experimental procedures were approved by the French health research ethics committee (CPP Ile de France VI, 2017-A02525–48). Funding for data collection was partly provided by Pulsalys grant R21036CC.

2.1.1. Study 1

A total sample of 2015 children aged between 3 and 11 years old (sex ratio = 1.01) was recruited at the French public kindergarten and primary schools of the South Gex region to collect age-normative values for the visual search screening test.

Among the total sample, a sub-sample of 69 children was recruited: 57 were below 8 years old (group A) and 12 were from 8 to 10 years old (group B) at first test. They were administered the same visual search screening test in the same conditions a second time between one and two years later.

2.1.2. Study 2

Among the total sample, 769 scholars of the 3rd, 4th and 5th grades also received an experimenter-blind assessment of their reading performance with the Alouette test ([Lefavrais, 1967](#)) when they were in their 4th or 5th grade, i.e. in the same scholar year or the year after (see [Table 1](#)).

2.2. Tasks, measures, and statistics

2.2.1. Study 1

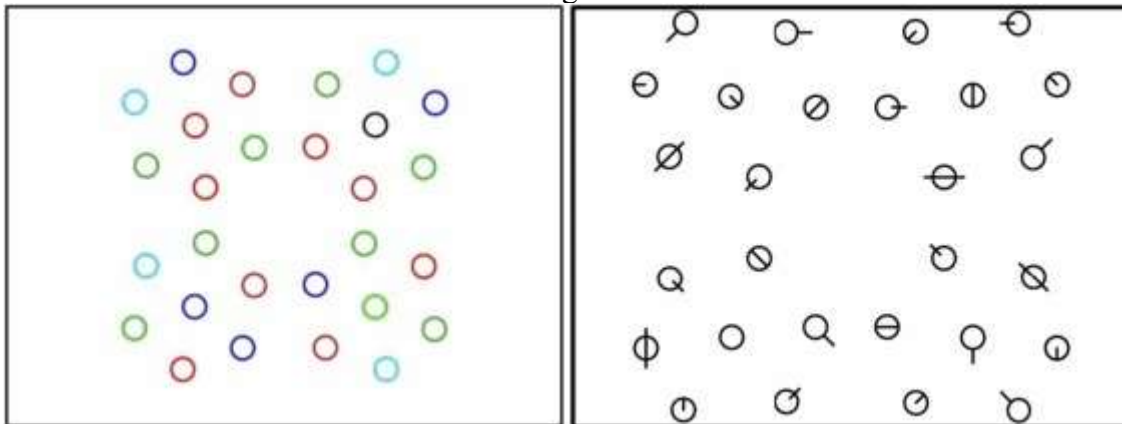
2.2.1.1. Task and measure

The visual search screening test consisted of 64 visual search displays where the participant was instructed to find and touch as fast as possible the (unique) black circle. The target (i.e., the black circle) was presented either among circles of various colours, or among black circles

combined with a bar of various length and location. Circles diameter was 1.6° for 35 cm eye-screen distance. The target could appear equally in the four quadrants and at 4 different eccentricities (10, 15, 20 and 25° from the centre for 35 cm eye-screen distance). For each trial, the software recorded the time at which the participant touched within a circular diameter of 3.7° visual degrees defined around the centre of the target location. This touch ended the trial. Then, an inter-trial display was presented, consisting of a centred black circle, to catch participant's attention and remind the target to be found, before visual search display presentation.

2.2.1.2. Administration protocol

The instructions were provided with example of protocol images printed on sheets of paper. The task was explained as follows: 'You have to find this black circle (showing the circle alone on a page), which will either be among other coloured circles or among other black circles, each of which are associated with a bar.' The child was shown two trial examples as paper images (one with coloured circles and one with symbols) and was asked to point toward the black circle on the laminated sheets. Once the experimenter has been ensured that the child understood this basic instruction by the child's pointing responses, the child was informed that he would perform in the same manner on the tablet until he finds all the 64 black circles hidden in the images, and that he has to be the fastest as possible (Fig. 2, supplementary information). It was also mentioned that the black circle will be presented alone in-between each search image, and that this one is just to look at, "to recall that you should find this same black circle in all images".



1. [Download: Download high-res image \(97KB\)](#)
2. [Download: Download full-size image](#)

Fig. 2. Examples of visual search displays. The unique visual target (the black circle) was presented among circles of various colours (left panel) versus among circles combined with a bar of various length and location (right panel).

Children were seated on height-adjustable stools to ensure a screen-to-eye distance of 35 cm, which was verified with a tape measure. The start signal is given, and the 'Start' button is pressed. The experimenter stays next to the child (on the right side) to ensure he remains focused throughout the test. If necessary, the experimenter can refocus and encourage the child. In case something happens in one trial leading to long pointing response time, those trials are removed by off-line analyses

2.2.1.3. Analyses

Off line analyses of each individual participant data consisted of extracting the median (Q50) and interquartile range (IQR) of the search times separately for colour and for symbol trials. Trials whose reaction times stood as outliers (farther to the mean reaction time than 2.5 times its variance) were suppressed from further analyses. The individual temporal gap (G) was then computed as followed:(1)

22

Both the temporal gap and the temporal gap variability varied with age (a). To get rid of these effects of age and compute standard scores corrected for age, the individual temporal gaps of the 2015 children were plotted by continuous ages ranging from 3 years old to 12 years old, and fitted using the sum of an exponential and a linear function as followed:(2)

where p_0 and p_3 drive the score of the temporal gap at the origin of the age axis, p_1 and p_2 drive the speed of decrease of the score when age increases. For the oldest ages, p_2a+p_3 is the value of the score when it reaches a rather flat plateau.

The residues (differences between the observed individual scores and the fit) were also adjusted by an exponential function:(3)

The temporal gap score corrected for the participant age (G_s) could thus be computed as followed:(4)

where R stands for residues. Bars upon variable letters stand for averages. The corrected temporal gap was arbitrary positioned at the averaged value of the raw scores and its variation matched the relative variation of each subject value to the average of the residues.

This procedure allowed to normalise the temporal gaps with respect to this developmental fit and its variability. A temporal gap value (G_s) independent from the age of the participant was then obtained. The test-retest reliability of this *standardized temporal gap* in a single individual over time was evaluated on a sub-sample of 69 children who were tested twice.

The reliability was statistically addressed in two ways: first, a correlation between the temporal gap measured at the first and the second session of test, and second, a Fischer exact test of the evolution of the temporal gap clinical categorisation in percentile between the two sessions, based on the fragility threshold (<75th centile).

2.2.2. Study 2

2.2.2.1. Reading task and measures

The reading task was the Alouette reading test ([Lefavrais, 1967](#)), a classical French test to screen for DD. It evaluates lexical decoding under normal reading conditions by using a text that is grammatically and syntactically correct, uses real words but is overall meaningless. This makes the predictability of content words very low. As a result, the Alouette Test does not provide contextual cues that the reader can use to compensate for decoding difficulties ([Torgesen & Rashotte, 2001](#)). The child was warned that the text is meaningless. The instruction was to read the text as best as possible for a period of time of 3 minutes. When the child was able to finish the text before this time limit, the experimenter collected the exact required duration. The experimenter also collected the number of reading errors and the number of words read. From these measures, the *reading inaccuracy* (or error rate) was computed as the number of errors divided by the total number of words read by the participant, and the *reading speed* as the number of words read by the participant divided by the reading time in seconds.

2.2.2.2. Statistical tests of the relationship between reading and visual search measures

We used the whole sample of 769 participants of 4th or 5th grade who performed both the screening visual search test and the Alouette reading test to evaluate the simple correlation

between the standardised temporal gap in visual search and the z-scores of reading performance computed as the standard deviation to the mean measured on our sample for each age category. This was first done separately for the z-scores of reading speed and of reading inaccuracy, and then for the *reading efficiency* z-scores which were calculated for each child as the mean of the speed and inaccuracy z-scores.

The standardised temporal gap and the reading measures were also extracted as percentiles for Chi-squares analyses performed on the observed distribution of the number of children in each cell of the table crossing two categorical variables: normal, fragile or pathological reading abilities at the Alouette test and normal, fragile or pathological temporal gap at the visual search screening test, corresponding to percentiles below the 75th, between the 75th and the 95th, or above the 95th, respectively. These percentiles were extracted from the standardised temporal gap of the visual search screening test on one side, and from the z-scores of reading speed, inaccuracy, and efficiency on the other side with $z > -.674$, $-1.65 < z < -0.674$ or $z < -1.65$ respectively. Significant Chi2 tests would demonstrate that the two categorical variables (reading parameters and visual abilities) are not independent, and thus that they are correlated.

We finally assessed the sensitivity and the specificity of the visual search screening test to detect a deficit at the Alouette test (as defined by a score superior to the 95th centile) on reading speed and reading error rate separately, as well as on reading efficiency parameter. For these analyses we set the threshold of the visual search screening test at the 75th centile (a score superior to the 75th centile was considered as potentially at risk).

3. Results

3.1. Study 1

3.1.1. Normalization of the visual search screening test

[Fig. 3](#) shows the evolution of temporal gap values defined by [Eq. \(1\)](#) as a function of participant age. [Fig. 4](#) shows the result ([Eq. \(4\)](#)) of the fit that eliminated this age dependency contained in [\(2\)](#), [\(3\)](#). In both figures, the magenta crosses denote the data included in the final normalization, and the black crosses denote the data defined as outliers. An iterative procedure was used to determine both the age-dependency fit and which data should be classified as outliers:

- 1.

A first fit following the procedure described in the Methods section was made to obtain age-independent standardized gaps,

- 2.

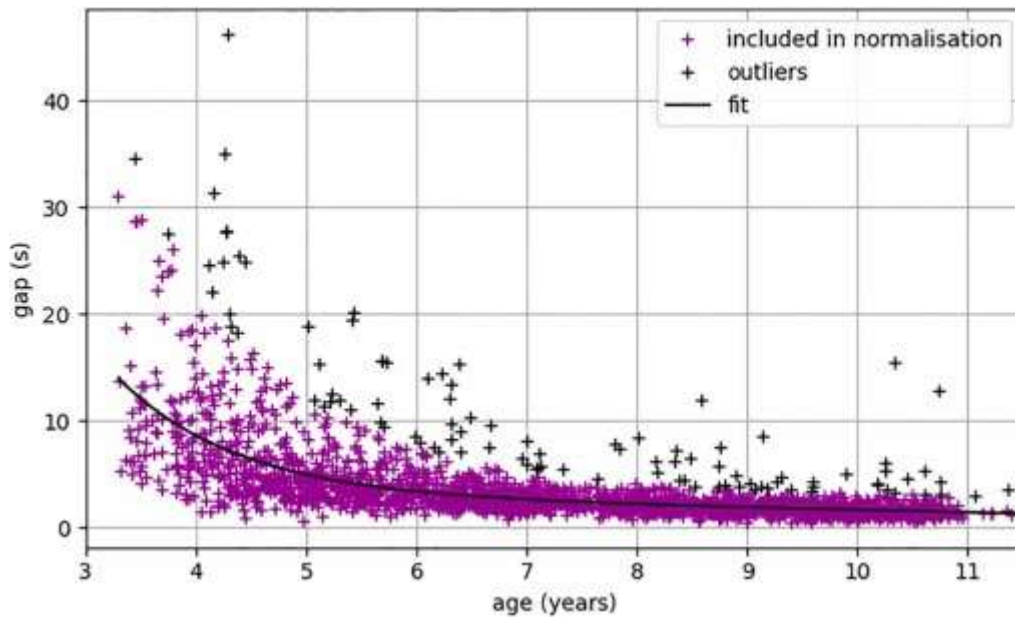
the mean and standard deviation of the standardized values were calculated,

- 3.

data whose values deviated by more than 2.5 standard deviations from the mean were classified as outliers and removed from the data for the next fit,

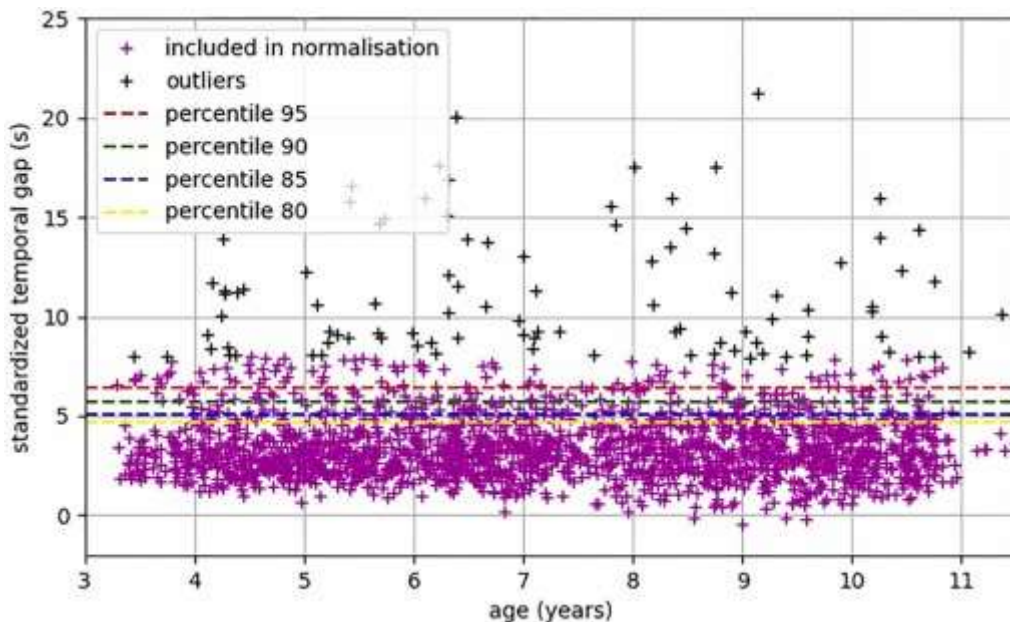
- 4.

steps 1. to 3. were repeated until there were no more outliers in step 3.



1. [Download: Download high-res image \(214KB\)](#)
2. [Download: Download full-size image](#)

Fig. 3. Temporal gap raw scores as a function of age. Black crosses stand for outliers scores excluded from the fit.

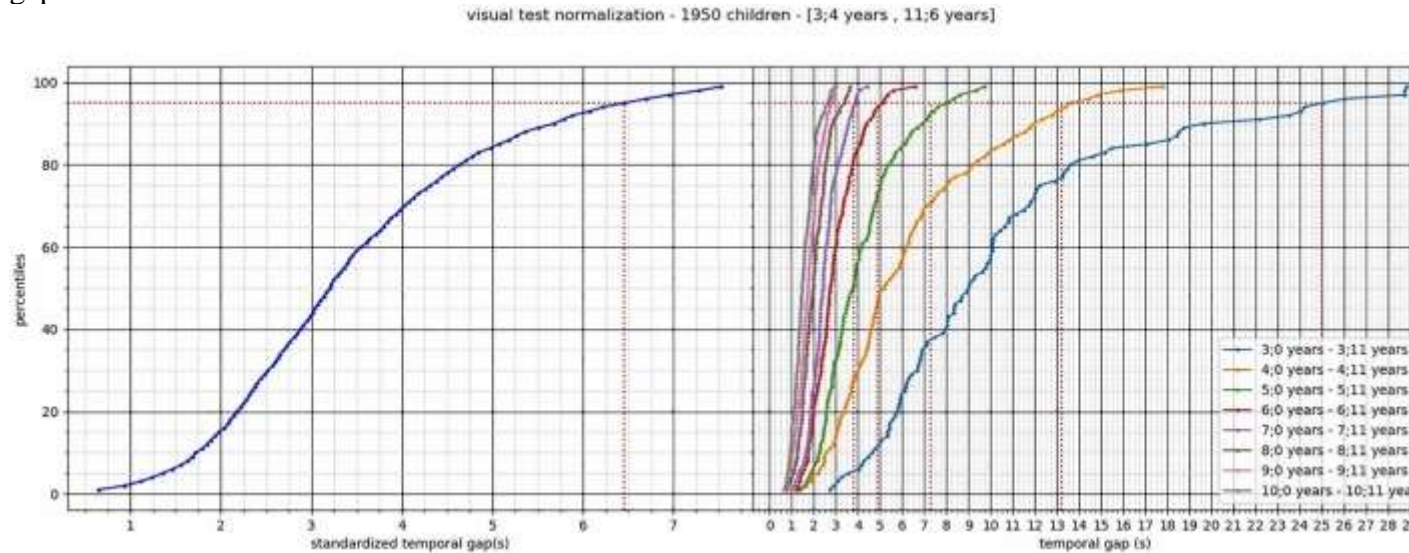


1. [Download: Download high-res image \(324KB\)](#)
2. [Download: Download full-size image](#)

Fig. 4. Standardized temporal gap as a function of age. Outliers are represented with black crosses. Colors Dash lines represent different percentile levels.

In this way, score normalization is achieved: the standardized gap is an age-independent variable with an equally age-independent variance.

Rapid tests, not shown here, demonstrated that the distribution of the standardized gaps was not gaussian like. The normalization is thus given as percentiles values. Fig. 5 shows these percentile values in two manners: either with a single line reflecting the standardized temporal gap or with several lines, corresponding to different age intervals, reflecting the temporal gaps.

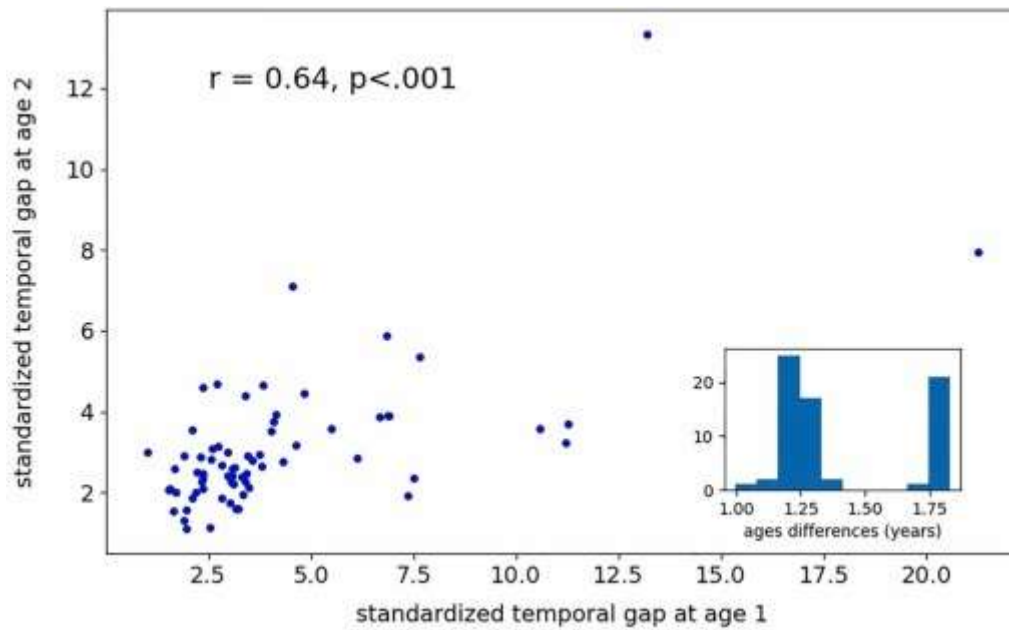


1. [Download: Download high-res image \(544KB\)](#)
2. [Download: Download full-size image](#)

Fig. 5. Percentiles and temporal gap correspondance. Left part shows the percentiles obtained for the standardized temporal gaps and right part shows those obtained for the age dependent temporal gaps for each age category. Red dotted lines represent the conventional 95th percentile limit.

3.1.2. Test- retest reliability

The visual search screening test was re-administered to sub-sample of 69 individuals with a delay between one and two years later (mean age difference= 1.75 year for the children of group A and 1.3 year for the children of group B). The significant positive correlation ($r = .64$, $p < .001$) between the temporal gap measured at the first and the second session is illustrated on Fig. 6. The inter-individual variability being not negligible, it was interesting to further explore possible changes of temporal gap clinical category between the two sessions of test. We defined fragility based on the 75th percentile limit and counted the number of children whose scores are on either side of this limit. Table 2 corresponds to the contingency table of the exact Fisher test performed to evaluate the possible independence between the temporal gap categories at the first and the second test sessions. The result reached the significance ($p = 0.01$). As can also be seen in the lower part of the Fig. 7, among the 11 children with fragile scores (<75th centile) at the first testing session, 6 also scored fragile at the second session. Conversely, only 4 subjects scored fragile at the second testing session but not at the first testing session. These results globally confirmed the dependence between the state of fragility measured at two different moments by the temporal gap and thus the satisfactory test-retest reliability of the visual search screening test.



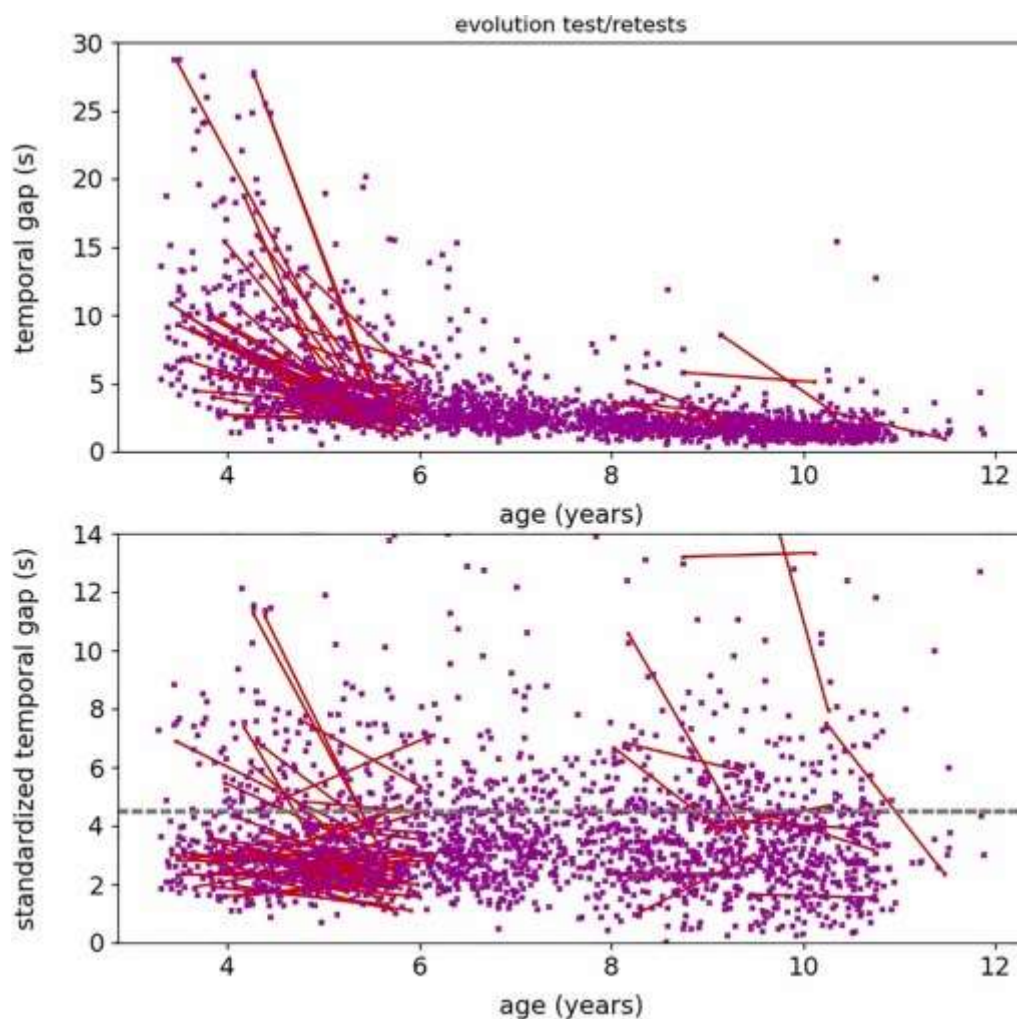
1. [Download: Download high-res image \(111KB\)](#)
2. [Download: Download full-size image](#)

Fig. 6. Correlation between standardized temporal gaps at two ages.

Table 2. Observed contingency table of the exact Fisher test performed to test the temporal gap categorisation at the first and the second test sessions.

Temporal Gap category 2nd normal 2nd fragile

1st normal	48	4
1st fragile	11	6



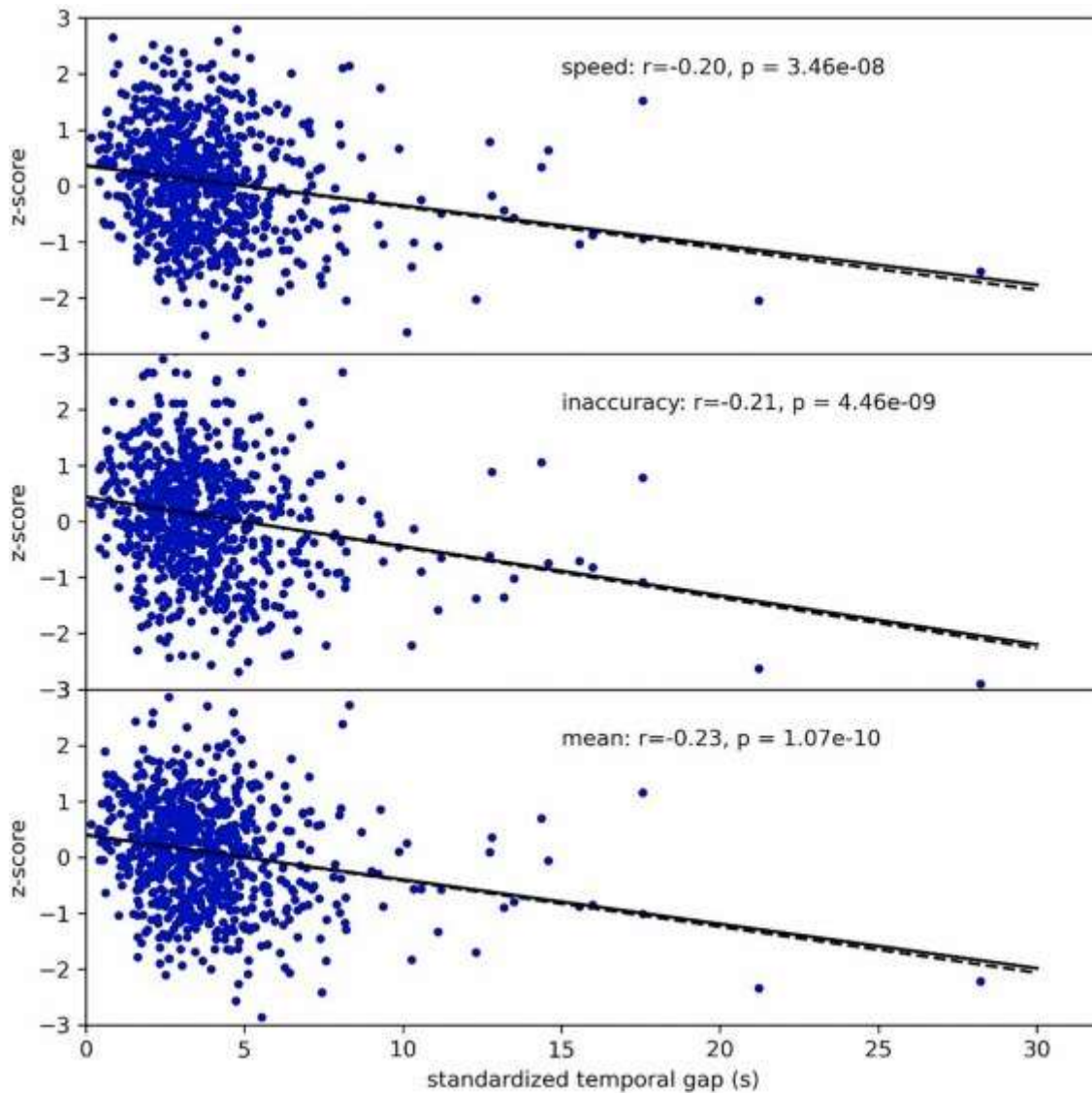
1. [Download: Download high-res image \(481KB\)](#)
2. [Download: Download full-size image](#)

Fig. 7. Test-Retest reliability. Upper figure shows all the couples of points used to evaluate the test-retest effect placing them in the whole normalisation data. Two populations have been targeted: young children between 4 and 6 years old and older ones between 8 and 12.

3.2. Study 2

3.2.1. Correlation between visual search and reading parameters

Simple correlations were significant between the standardised temporal gap and the z-scores of reading speed ($r = -0.20$, $p = 3.46 \times 10^{-8}$), reading inaccuracy ($r = -0.21$, $p = 4.46 \times 10^{-9}$), and reading efficiency ($r = -0.23$, $p = 1.07 \times 10^{-10}$). Note that these significant correlations were not driven only by the higher temporal gap values. Indeed, the correlations remained significant when we selected only the values of the standardised temporal gap less than 20 s: the dashed line was very similar to the full line of regression on [Fig. 8](#) for reading speed ($r = -0.17$, $p = 2.54 \times 10^{-6}$), reading inaccuracy ($r = -0.18$, $p = 8.70 \times 10^{-7}$), and reading efficiency ($r = -0.20$, $p = 4.70 \times 10^{-8}$).



1. [Download: Download high-res image \(398KB\)](#)
2. [Download: Download full-size image](#)

Fig. 8. Correlations between the standardized temporal gap and reading variables. The two lines represent the regression lines obtained in two conditions: all points (full line), only gap < 20 s (dashed line).

3.2.2. Comparison between centile categorisation of performance in the visual search screening test and in the reading test

Another way to test the relationship between visual search and reading performance was to statistically compare the hierarchical centile position of children along these variables. [Table 3](#) shows the observed contingency tables which represent the distribution of the sample along three categories. “Fragile” and “pathological” terms correspond to the thresholds defined in the methods section (75th and 95th percentiles, respectively). χ^2 tests demonstrated that the visual search screening test performance and the reading performance were not independent, for reading speed ($\chi^2(4) = 21.73$, $p = 0.01$) and reading inaccuracy ($\chi^2(4) = 35.8$, $p < 0.0001$) separately, and for reading efficiency ($\chi^2(4) = 32.09$, $p < 0.0002$).

Table 3. Observed contingency table of reading speed, inaccuracy and efficiency versus visual search screening test.

Empty Cell	Empty Cell	Visual search screening test				Empty Cell
Empty Cell		Pathological	Fragile	Normal	All	
Reading speed	Pathological	5	10	8	23	
	Fragile	22	<i>40</i>	107	169	
	Normal	<i>41</i>	<i>115</i>	421	577	
	All	68	165	536	769	
Empty Cell		Visual search screening test				
Empty Cell		Pathological	Fragile	Normal	All	
Reading inaccuracy	Pathological	8	17	18	43	
	Fragile	23	<i>39</i>	86	148	
	Normal	<i>37</i>	<i>109</i>	432	578	
	All	68	165	536	769	
Empty Cell		Visual search screening test				
Empty Cell		Pathological	Fragile	Normal	All	
Reading efficiency	Pathological	6	9	9	24	
	Fragile	23	<i>41</i>	84	147	
	Normal	<i>40</i>	<i>115</i>	443	598	
	All	68	165	536	769	

3.2.3. Specificity and sensitivity of the visual search screening test

We also assessed the specificity/sensitivity of the visual search screening test to detect reading deficit. Poor visual search performance threshold was chosen at 75th centile and the threshold score above which a child is considered to have significant reading deficit was defined at percentile 95. In [Table 3](#), true positive are in bold, true negative are underlined, false positive are in italics and false negative are in light grey. With these thresholds, the sensitivity of the visual screening test with the reading inaccuracy criterium was 58 % and its specificity was 71 %. With the reading speed criterium, the sensitivity of the visual search test was 65 % and the specificity was 71 %. With the reading efficiency criterium, the sensitivity of the visual search test was 63 % and the specificity was 71 %.

4. Discussion

Studies measuring pre-reading visual ability at 5 years old, and testing reading abilities in first grade, have revealed that VA parameters are promising predictors of reading acquisition difficulties ([Franceschini et al., 2012](#), [Valdois et al., 2019b](#), [Vernet et al., 2022](#)). This suggests that learning to read implies not only good language skills, but also VA prerequisite. It requires good perceptual discrimination and integration of the relative length, orientation and location of the different visual components of letters, and later of the relative positions of letters and words along strings, which are simultaneous but ordered visual presentations to scan. However, about one third of 5 years old children display inefficient oculomotor and visuo-perceptual abilities, without any clinical complaints, which is nevertheless reflected by slower and more inaccurate reading performance one year later ([Vernet et al., 2022](#)). Even

earlier tests of pre-reading visual abilities are thus needed to propose specific VA training programs in kindergarten for children at risk before the first grade and prevent delay in reading acquisition and its consequences on self-esteem and behaviour at school.

Previous results ([Casco and Prunetti, 1996](#), [Marendaz et al., 1996](#), [Vialatte et al., 2023a](#)) suggested that a specific slowness of search for a target distinguished by a lacking element in a symbol may be linked to poor reading performance. In the present paper, we report two studies starting the validation of such specific screening test as predictor of reading performance. It involved the visual search of a black disk among distracters that either consisted of coloured disks or of graphic symbols made up by the spatial combination of a black disk and a bar ([Fig. 2](#)).

In the first study, we confirmed its feasibility from 3 to 11 years old and provided the developmental norms for our measure - the temporal gap between colour and symbol search - which decreased with age. In a sub-sample of 69 children of various age, this measure displayed a good statistical test-retest reliability at the group level. At the individual level, with a threshold set at 75th centile, 48 of these children reliably scored non-fragile at both testing sessions and 6 children remained fragile when tested twice. For the 15 remaining children, the fragile or non-fragile classification differed between the first and second testing sessions, which can be considered as a limitation of this first study. However, note that for most of them ($n = 11$) the change was observed in the direction of a first measure classified as fragile and a second measure classified as normalised. We think that such false positive rate is suitable for a test aiming for a large screening with the highest and earliest sensitivity to orient attention toward a group of children that would benefit from a higher degree of visuo-spatial and visuo-attentional training games prior to literacy instruction.

In the second study, we evaluated the validity of a large temporal gap in the visual screening test to predict poor reading performance among a large population of 4th and 5th grades children. We established that the temporal gap between colour and symbol visual search significantly correlated with text reading efficiency with coefficient of 0.23 ($r = 0.20$ and $r = 0.21$ for reading speed and accuracy, respectively). The relationship between visual search and reading performance was confirmed by an additional analysis comparing the distribution of our sample along three clinical visual and reading categories (normal, fragile and pathological). Finally, the visual search screening test obtained 71 % specificity and 63 % sensitivity for predicting difficulties at the Alouette reading test, with visual performance threshold chosen at percentile 75th and reading efficiency threshold defined at percentile 95th. Although some caution is required due to a non-negligible number of false positives, this good specificity tended to confirm our hypothesis that those scoring at the lowest quartile at the visual test would suffer significant VA reading difficulties. Since the Alouette reading test does not allow to distinguish between sub-types of DD, we did not expect a high sensitivity value. Indeed, children with a good performance in the visual search screening test could still present DD due to pathological phonological awareness for example, and thus constitute false negatives. False positives and false negatives would be problematic for a diagnostic test of DD, whose validation would also require both to combine the temporal gap measure with other cognitive and phonological metrics and to measure reading performance not only with text, but also with word, pseudoword or non-word lists. However, we think that the observed sensitivity and specificity is adapted for a screening test, aiming at allowing 1) children already diagnosed with DD to benefit from VA remediation in the context of their follow-up (if used by clinicians) or 2) children at risk to benefit from more intensive training of the visual prerequisites for reading acquisition from teachers (if used in the scholar context). Several other limitations could be raised. First, when requesting consent, we did not ask parents for visual data (such as the prescription of their child's glasses) or whether their child has previously undergone a hearing test. Second, while we were in an area known for its high

level of bilingualism, we only excluded all newly arrived children (those who have been in France for less than two years). Third, we did not administer phonological tests, which would have allowed us to gain a deeper understanding of our sample, particularly in terms of false negatives (children who have no difficulty on the VA measure but have reading difficulties). Last, even though the temporal gap correlated with reading efficiency, as well as with both reading speed and accuracy separately, the observed correlation coefficients can be considered low. As reading is multifactorial, it is logical that a single predictor displays a low correlation coefficient. Nevertheless, in the study of [Valdois et al. \(2021\)](#), phonological and VA predictors displayed stronger zero-order correlation coefficients with reading efficiency of a shorter (100-words) and meaningful text in 6th grade children: r was 0.31 for phoneme deletion, 0.33 for spoonerisms, 0.52 for rapid digits naming, 0.37 and 0.25 for the VA span assessed via global and partial report, respectively. As it assessed several – VA and phonological – predictors, this study also had the methodological advantage of allowing for direct comparison between them and for multiple regression analyses, but with a unique reading measure. Some studies rather analysed the correlation with reading accuracy and speed separately; as an example, in the [Zoubrinetzky et al. \(2016\)](#) study, which involved children of similar age as ours, reading speed correlated significantly with the VA span score ($r = -0.31$) but not with phonological awareness ($r = 0.02$), while reading accuracy correlated significantly with phonological awareness ($r = 0.27$) but not with the VA span score ($r = 0.22$). In conclusion, the present investigation provided age-normative values of the visual search screening test with a developmental trajectory starting at 3 years old, as well as its test-retest reliability (study 1) and established its relationship with reading performance in children of 4th and 5th grades (study 2). At this age, the diagnosis of DD is already possible. However, for more efficient remediation, it is relevant to best define the cognitive profile of a patient. To this aim, the visual search screening test makes a useful clinical tool to detect whether a child with DD presents fragile VA abilities prone to contribute to his/her reading difficulties. This would allow a child diagnosed with DD to benefit from specific VA remediation (e.g. [Bertoni et al., 2024](#); [Vialatte et al., 2023b](#); [Franceschini et al., 2022](#), [Franceschini et al., 2017](#); [Antzaka et al., 2017](#)). For example, a training program involving visual search of letter among various symbols has been shown to enhance reading accuracy in 8-to-12-year old children with DD ([Vialatte et al., 2023b](#)). Interestingly, such VA training program would be feasible as early as kindergarten, as visual search does not require the knowledge of letters but solely their visual discrimination among distractors ([Treisman & Gelade, 1980](#)).

CRediT authorship contribution statement

Audrey Vialatte: Original draft, Investigation, Methodology. **Eric Chabanat:** Formal analysis, Original draft, Investigation, Methodology. **Agnes Witko:** Original draft, Investigation. **Laure Pisella:** Writing – original and final draft, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization.

Appendix A. Supplementary material

Media player

0 seconds

0:00 / 0:13 Speed: 1x Stopped

[Download: Download video \(980KB\)](#)

Supplementary material

Data Availability

The data that has been used is confidential.

References

1. [Aghababian and Nazir, 2000](#)

V. Aghababian, T.A. Nazir

Developing normal reading skills: Aspects of the visual processes underlying word recognition

Journal of Experimental Child Psychology, 76 (2000), pp. 123-150,
[10.1006/jecp.1999.2540](https://doi.org/10.1006/jecp.1999.2540)

[View PDF](#)[View article](#)[View in Scopus](#)[Google Scholar](#)[Antzaka et al., 2017](#)

A. Antzaka, M. Lallier, S. Meyer, J. Diard, M. Carreiras, S. Valdois

Enhancing reading performance through action video games: The role of visual attention span
Scientific Reports, 7 (1) (2017), Article 14563, [10.1038/s41598-017-15119-9](https://doi.org/10.1038/s41598-017-15119-9)

[View in Scopus](#)

[Google Scholar](#)[Bedoin, 2017](#)

N. Bedoin

Rééquilibrer les analyses visuo-attentionnelles globales et locales pour améliorer la lecture
chez des enfants dyslexiques de surface

ANAE, 19 (2017), pp. 276-294

[View in Scopus](#)

[Google Scholar](#)[Bellocchi et al., 2017](#)

S. Bellocchi, M. Muneaux, A. Huau, Y. Lévêque, M. Jover, S. Ducrot

Exploring the link between visual perception, visual-motor integration, and reading in normal
developing and impaired children using DTVP-2

Dyslexia, 23 (3) (2017), pp. 296-315, [10.1002/dys.1561](https://doi.org/10.1002/dys.1561)

[View in Scopus](#)

[Google Scholar](#)[Bertoni et al., 2024](#)

S. Bertoni, S. Franceschini, M. Mancarella, G. Puccio, L. Ronconi, G. Marsicano, S. Gori, G.
Campana, A. Facoetti

Action video games and posterior parietal cortex neuromodulation enhance both attention and
reading in adults with developmental dyslexia

Cerebral Cortex, 34 (4) (2024), Article bhae152, [10.1093/cercor/bhae152](https://doi.org/10.1093/cercor/bhae152)

[View in Scopus](#)[Google Scholar](#)[Casco and Prunetti, 1996](#)

C. Casco, E. Prunetti

Visual search of good and poor readers: Effects with targets having single and combined
features

Perceptual and Motor Skills, 82 (3_) (1996), [10.2466/pms.1996.82.3c.1155](https://doi.org/10.2466/pms.1996.82.3c.1155)

[Google Scholar](#)

[Castles and Coltheart, 1993](#)

A. Castles, M. Coltheart

Varieties of developmental dyslexia

Cognition, 47 (2) (1993), pp. 149-180, [10.1016/0010-0277\(93\)90003-e](https://doi.org/10.1016/0010-0277(93)90003-e)

[View PDF](#)[View article](#)[View in Scopus](#)[Google Scholar](#)

- [Chall, 1983](#)

J.S. Chall

Stages of reading development

McGraw-Hill, New York (1983)

[Google Scholar](#)

[Facoetti et al., 2010](#)

A. Facoetti, A.N. Trussardi, M. Ruffino, M.L. Lorusso, C. Cattaneo, R. Galli, M. Molteni, M. Zorzi

Multisensory spatial attention deficits are predictive of phonological decoding skills in developmental dyslexia

Journal of Cognitive Neuroscience, 22 (5) (2010), pp. 1011-1025, [10.1162/jocn.2009.21232](https://doi.org/10.1162/jocn.2009.21232)

[View in Scopus](#)[Google Scholar](#)[Franceschini et al., 2017](#)

S. Franceschini, S. Bertoni, T. Gianesini, S. Gori, A. Facoetti

A different vision of dyslexia: Local precedence on global perception

Scientific Reports, 7 (1) (2017), Article 17462, [10.1038/s41598-017-17626-1](https://doi.org/10.1038/s41598-017-17626-1)

[View in Scopus](#)

[Google Scholar](#)[Franceschini et al., 2022](#)

S. Franceschini, S. Bertoni, G. Puccio, S. Gori, C. Termine, A. Facoetti

Visuo-spatial attention deficit in children with reading difficulties

Scientific Reports, 12 (1) (2022), Article 13930, [10.1038/s41598-022-16646-w](https://doi.org/10.1038/s41598-022-16646-w)

[View in Scopus](#)

[Google Scholar](#)[Franceschini et al., 2012](#)

S. Franceschini, S. Gori, M. Ruffino, K. Pedrolli, A. Facoetti

A causal link between visual spatial attention and reading acquisition

Current Biology, 22 (9) (2012), pp. 814-819, [10.1016/j.cub.2012.03.013](https://doi.org/10.1016/j.cub.2012.03.013)

[View PDF](#)[View article](#)[View in Scopus](#)[Google Scholar](#)[Goswami, 2015](#)

U. Goswami

Visual attention span deficits and assessing causality in developmental dyslexia

Nature Reviews Neuroscience, 16 (4) (2015), [10.1038/nrn3836-c2](https://doi.org/10.1038/nrn3836-c2)

[Google Scholar](#)

- [Hulme, 1987](#)

C. Hulme

Reading retardation

In: J.R. Beech, A.M. Colley (Eds.), Cognitive approaches to reading, Wiley (1987), pp. 94-128

[Google Scholar](#)

[Iversen et al., 2005](#)

S. Iversen, K. Berg, B. Ellertsen, F.-E. Tønnessen

Motor coordination difficulties in a municipality group and in a clinical sample of poor readers

Dyslexia (Chichester, England), 11 (3) (2005), pp. 217-231, [10.1002/dys.297](https://doi.org/10.1002/dys.297)

[View in Scopus](#)

[Google Scholar](#)[Kevan and Pammer, 2009](#)

A. Kevan, K. Pammer

Predicting early reading skills from pre-reading measures of dorsal stream functioning

Neuropsychologia, 47 (14) (2009), pp. 3174-3181, [10.1016/j.neuropsychologia.2009.07.016](https://doi.org/10.1016/j.neuropsychologia.2009.07.016)

[View PDF](#)[View article](#)[View in Scopus](#)[Google Scholar](#)[Khan et al., 2016](#)

A.Z. Khan, M. Prost-Lefebvre, R. Salemme, G. Blohm, Y. Rossetti, C. Tilikete, L. Pisella
The attentional fields of visual search in simultanagnosia and healthy individuals: How object
and space attention interact

Cerebral Cortex (New York, N Y: 1991), 26 (3) (2016), [10.1093/cercor/bhv059](https://doi.org/10.1093/cercor/bhv059)

[Google Scholar](#)

[LaBerge and Samuels, 1974](#)

D. LaBerge, S.J. Samuels

Toward a theory of automatic information processing in reading

Cognitive Psychology, 6 (1974), pp. 293-323, [10.1016/0010-0285\(74\)90015-2](https://doi.org/10.1016/0010-0285(74)90015-2)

[View PDFView articleView in ScopusGoogle Scholar](#)

• [Lefavrais, 1967](#)

P. Lefavrais

*Manuel du test de l'alouette: [Test psychologique]: Test d'analyse de la lecture et de la
dyslexie / Pierre Lefavrais* ([2. éd

Centre de psychologie appliquée (1967)

[Google Scholar](#)

[Liu et al., 2022](#)

T. Liu, M. Thiebaut de Schotten, I. Altarelli, F. Ramus, J. Zhao

Neural dissociation of visual attention span and phonological deficits in developmental
dyslexia: A hub-based white matter network analysis

Human Brain Mapping, 43 (17) (2022), pp. 5210-5219, [10.1002/hbm.25997](https://doi.org/10.1002/hbm.25997)

[View in Scopus](#)

[Google ScholarLobier et al., 2012](#)

M. Lobier, C. Peyrin, J.-F. Le Bas, S. Valdois

Pre-orthographic character string processing and parietal cortex: A role for visual attention in
reading?

Neuropsychologia, 50 (9) (2012), pp. 2195-2204, [10.1016/j.neuropsychologia.2012.05.023](https://doi.org/10.1016/j.neuropsychologia.2012.05.023)

[View PDFView articleView in ScopusGoogle ScholarLobier et al., 2014](#)

M. Lobier, C. Peyrin, C. Pichat, J.-F. Le Bas, S. Valdois

Visual processing of multiple elements in the dyslexic brain: Evidence for a superior parietal
dysfunction

Frontiers in Human Neuroscience, 8 (2014), p. 479, [10.3389/fnhum.2014.00479](https://doi.org/10.3389/fnhum.2014.00479)

[View in Scopus](#)

[Google ScholarLobier and Valdois, 2015](#)

M. Lobier, S. Valdois

Visual attention deficits in developmental dyslexia cannot be ascribed solely to poor reading
experience

Nature Reviews Neuroscience, 16 (4) (2015), p. 225, [10.1038/nrn3836-c1](https://doi.org/10.1038/nrn3836-c1)

[View in Scopus](#)

[Google ScholarMarendaz et al., 1996](#)

C. Marendaz, S. Valdois, J.-P. Walch

Dyslexie développementale et attention visuo-spatiale

L'année psychologique, 96 (2) (1996), pp. 193-224, [10.3406/psy.1996.28893](https://doi.org/10.3406/psy.1996.28893)

[View in ScopusGoogle ScholarMuneaux and Ducrot, 2014](#)

M. Muneaux, S. Ducrot

Capacités oculomotrices, visuo-attentionnelles et lecture: Un autre regard sur la dyslexie...

A N A E Approche neuropsychologique des apprentissages chez l'Enfant, 129 (2014), pp.
137-146

[View in Scopus](#)

[Google ScholarNicolson and Fawcett, 1994](#)

R.I. Nicolson, A.J. Fawcett

Comparison of deficits in cognitive and motor skills among children with dyslexia
Annals of Dyslexia, 44 (1) (1994), pp. 147-164, [10.1007/BF02648159](https://doi.org/10.1007/BF02648159)

[View in Scopus](#)

[Google Scholar](#)[Peyrin et al., 2011](#)

C. Peyrin, J.F. Démonet, M.A. N'Guyen-Morel, J.F. Le Bas, S. Valdois
Superior parietal lobule dysfunction in a homogeneous group of dyslexic children with a visual attention span disorder

Brain and Language, 118 (3) (2011), pp. 128-138, [10.1016/j.bandl.2010.06.005](https://doi.org/10.1016/j.bandl.2010.06.005)

[View PDF](#)[View article](#)[View in Scopus](#)[Google Scholar](#)[Peyrin et al., 2012](#)

C. Peyrin, M. Lallier, J.F. Démonet, C. Pernet, M. Baciou, J.F. Le Bas, S. Valdois
Neural dissociation of phonological and visual attention span disorders in developmental dyslexia: fMRI evidence from two case reports

Brain and Language, 120 (3) (2012), pp. 381-394, [10.1016/j.bandl.2011.12.015](https://doi.org/10.1016/j.bandl.2011.12.015)

[View PDF](#)[View article](#)[View in Scopus](#)[Google Scholar](#)[Pisella et al., 2021](#)

L. Pisella, A. Vialatte, M. Martel, M. Prost-Lefebvre, M.-C. Caton, M. Stalder, R. Yssad, A.C. Roy, C. Vuillerot, S. Gonzalez-Monge

Elementary visuospatial perception deficit in children with neurodevelopmental disorders
Developmental Medicine and Child Neurology, 63 (4) (2021), pp. 457-464,

[10.1111/dmcn.14743](https://doi.org/10.1111/dmcn.14743)

[View in Scopus](#)

[Google Scholar](#)[Reilhac et al., 2013](#)

C. Reilhac, C. Peyrin, J.-F. Démonet, S. Valdois

Role of the superior parietal lobules in letter-identity processing within strings: fMRI evidence from skilled and dyslexic readers

Neuropsychologia, 51 (4) (2013), pp. 601-612, [10.1016/j.neuropsychologia.2012.12.010](https://doi.org/10.1016/j.neuropsychologia.2012.12.010)

[View PDF](#)[View article](#)[View in Scopus](#)[Google Scholar](#)[Rutter and Yule, 1975](#)

M. Rutter, W. Yule

The concept of specific reading retardation

Journal of Child Psychology and Psychiatry, and Allied Disciplines, 16 (3) (1975), pp. 181-197, [10.1111/j.1469-7610.1975.tb01269.x](https://doi.org/10.1111/j.1469-7610.1975.tb01269.x)

[View in Scopus](#)

[Google Scholar](#)[Saksida et al., 2016](#)

A. Saksida, S. Iannuzzi, C. Bogliotti, Y. Chaix, J.-F. Démonet, L. Bricout, C. Billard, M.-A. Nguyen-Morel, M.-F. Le Heuzey, I. Soares-Boucaud, F. George, J.C. Ziegler, F. Ramus
Phonological skills, visual attention span, and visual stress in developmental dyslexia

Developmental Psychology, 52 (10) (2016), pp. 1503-1516, [10.1037/dev0000184](https://doi.org/10.1037/dev0000184)

[View in Scopus](#)[Google Scholar](#)

• [Torgesen and Rashotte, 2001](#)

J.K. Torgesen, C.A. Rashotte

Relationships with 'Established empirical outcomes'

Dyslexia, fluency, and the brain, York Press (2001), p. 423

[Google Scholar](#)

[Treisman and Gelade, 1980](#)

A.M. Treisman, G. Gelade

A feature-integration theory of attention

Cognitive Psychology, 12 (1) (1980), pp. 97-136, [10.1016/0010-0285\(80\)90005-5](https://doi.org/10.1016/0010-0285(80)90005-5)

[View PDF](#)[View article](#)[View in Scopus](#)[Google Scholar](#)[Valdois et al., 2011](#)

S. Valdois, C. Bidet-Ildei, D. Lassus-Sangosse, C. Reilhac, M.-A. N'guyen-Morel, E. Guinet, J.-P. Orliaguet

A visual processing but no phonological disorder in a child with mixed dyslexia
Cortex; a Journal Devoted to the Study of the Nervous System and Behavior, 47 (10) (2011), pp. 1197-1218, [10.1016/j.cortex.2011.05.011](https://doi.org/10.1016/j.cortex.2011.05.011)
[View PDF](#)[View article](#)[View in Scopus](#)[Google Scholar](#)[Valdois et al., 2003](#)

S. Valdois, M.-L. Bosse, B. Ans, S. Carbonnel, M. Zorman, D. David, J. Pellat
Phonological and visual processing deficits can dissociate in developmental dyslexia: Evidence from two case studies
Reading and Writing, 16 (6) (2003), pp. 541-572, [10.1023/A:1025501406971](https://doi.org/10.1023/A:1025501406971)
[View in Scopus](#)
[Google Scholar](#)[Valdois et al., 2019a](#)

S. Valdois, D. Lassus-Sangosse, M. Lallier, O. Moreaud, L. Pisella
What bilateral damage of the superior parietal lobes tells us about visual attention disorders in developmental dyslexia
Neuropsychologia, 130 (2019), pp. 78-91, [10.1016/j.neuropsychologia.2018.08.001](https://doi.org/10.1016/j.neuropsychologia.2018.08.001)
[View PDF](#)[View article](#)[View in Scopus](#)[Google Scholar](#)[Valdois et al., 2021](#)

S. Valdois, C. Reilhac, E. Ginestet, M. Line Bosse
Varieties of Cognitive Profiles in Poor Readers: Evidence for a VAS-Impaired Subtype
Journal of Learning Disabilities, 54 (3) (2021), pp. 221-233, [10.1177/0022219420961332](https://doi.org/10.1177/0022219420961332)
[View in Scopus](#)
[Google Scholar](#)[Valdois et al., 2019b](#)

S. Valdois, J.-L. Roulin, M.-L. Bosse
Visual attention modulates reading acquisition
Vision Research, 165 (2019), pp. 152-161, [10.1016/j.visres.2019.10.011](https://doi.org/10.1016/j.visres.2019.10.011)
[View PDF](#)[View article](#)[View in Scopus](#)[Google Scholar](#)[Velay et al., 2002](#)

J.-L. Velay, V. Daffaure, K. Giraud, M. Habib
Interhemispheric sensorimotor integration in pointing movements: A study on dyslexic adults
Neuropsychologia, 40 (7) (2002), pp. 827-834, [10.1016/s0028-3932\(01\)00177-4](https://doi.org/10.1016/s0028-3932(01)00177-4)
[View PDF](#)[View article](#)[View in Scopus](#)[Google Scholar](#)[Vernet et al., 2022](#)

M. Vernet, S. Bellocchi, L. Leibnitz, Y. Chaix, S. Ducrot
Predicting future poor readers from pre-reading visual skills: A longitudinal study
Applied Neuropsychology Child, 11 (3) (2022), pp. 480-494, [10.1080/21622965.2021.1895790](https://doi.org/10.1080/21622965.2021.1895790)
[View in Scopus](#)
[Google Scholar](#)[Vialatte et al., 2023b](#)

A. Vialatte, P.-E. Aguera, N. Bedoin, A. Witko, E. Chabanat, L. Pisella
Enhancing reading accuracy through visual search training using symbols
Scientific Reports, 13 (1) (2023), p. 4291, [10.1038/s41598-023-31037-5](https://doi.org/10.1038/s41598-023-31037-5)
[View in Scopus](#)
[Google Scholar](#)[Vialatte et al., 2023a](#)

A. Vialatte, E. Chabanat, A. Witko, L. Pisella
Toward the characterization of a visual form of developmental dyslexia: Reduced visuo-attentional capacity for processing multiple stimuli made of separable features
Cognitive Neuropsychology, 40 (3-4) (2023), pp. 186-213, [10.1080/02643294.2023.2266179](https://doi.org/10.1080/02643294.2023.2266179)
[View in Scopus](#)
[Google Scholar](#)[Vialatte et al., 2021a](#)

A. Vialatte, R. Salemme, A.Z. Khan, L. Pisella
Attentional limits in visual search with and without dorsal parietal dysfunction: Space-based window or object-based span?
Neuropsychologia, 161 (2021), Article 108013, [10.1016/j.neuropsychologia.2021.108013](https://doi.org/10.1016/j.neuropsychologia.2021.108013)
[View PDF](#)[View article](#)[View in Scopus](#)[Google Scholar](#)[Vialatte et al., 2021b](#)

A. Vialatte, Y. Yeshurun, A.Z. Khan, R. Rosenholtz, L. Pisella
Superior parietal lobule: A role in relative localization of multiple different elements
Cerebral Cortex (New York, N Y: 1991), 31 (1) (2021), pp. 658-671, [10.1093/cercor/bhaa250](https://doi.org/10.1093/cercor/bhaa250)

[View in Scopus](#)

[Google Scholar](#)[Vidyasagar and Pammer, 2010](#)

T.R. Vidyasagar, K. Pammer

Dyslexia: A deficit in visuo-spatial attention, not in phonological processing

Trends in Cognitive Sciences, 14 (2) (2010), pp. 57-63, [10.1016/j.tics.2009.12.003](https://doi.org/10.1016/j.tics.2009.12.003)

[View PDF](#)[View article](#)[View in Scopus](#)[Google Scholar](#)[Wolpert, 1924](#)

I. Wolpert

Die simultanagnosie—Störung der gesamtauffassung

Zeitschrift für die gesamte Neurologie und Psychiatrie, 93 (1) (1924), pp. 397-415,

[10.1007/BF02900065](https://doi.org/10.1007/BF02900065)

[View in Scopus](#)

[Google Scholar](#)[Zoubrinetzky et al., 2014](#)

R. Zoubrinetzky, F. Bielle, S. Valdois

New insights on developmental dyslexia subtypes: Heterogeneity of mixed reading profiles

PloS One, 9 (6) (2014), Article e99337, [10.1371/journal.pone.0099337](https://doi.org/10.1371/journal.pone.0099337)

[View in Scopus](#)

[Google Scholar](#)[Zoubrinetzky et al., 2016](#)

R. Zoubrinetzky, G. Collet, W. Serniclaes, M.-A. Nguyen-Morel, S. Valdois

Relationships between categorical perception of phonemes, phoneme awareness, and visual attention span in developmental dyslexia

PloS One, 11 (3) (2016), Article e0151015, [10.1371/journal.pone.0151015](https://doi.org/10.1371/journal.pone.0151015)

[View at publisher](#)[View in Scopus](#)

[Google Scholar](#)