Could Preschool Eye Movements Contribute to Diagnosis of Reading and/or Dyslexia? A Longitudinal Case Study

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The author studied the relationship between eye movements of a preschool child (boy) and his subsequent development as a reader. The aim was to contribute to findings about whether there is information within eye movements about future reading development and its anomalies. The case report showed that long-term, partial weakening of eye movements correlated with long-term, partial weakening of reading development. With caution it can be stated that examinations of eye movements may contribute to prognostic considerations in the field of reading development and may become part of preschool screening.

Keywords: dyslexia, reading, eye movements

Diagnosis code 315.0 in DSM-IV-TR specifies the following criteria for dyslexia: A. Reading performance is significantly lower than expected for that particular chronological age, IQ and education; B. The reading disorder interferes with school performance or general activities which require reading skills; C. In differential diagnostics, it is necessary to eliminate the following from the list of reading disorder causes: mental retardation, sensory disorders, neurological illness and other general health ailments, including emotional neglect.

The etiology of dyslexia is still unclear. The prevailing opinion is that the disorder is of neurobiological origin (e.g. Bakker, Van Strien, & Licht, 2007; Bucci, Brémon-Gignac, & Kapoula, 2008; Galaburda, 2005; Wiseheart, Altmann, Park, & Lombardino, 2009).

According to phonological theory, the essential problem is so-called phoneme awareness (Liberman, 1984). This is the ability to identify parts of a word, phonemes, in the word as a phonetic whole. Each phoneme has a particular grapheme (i.e. letter) assigned to it. While reading, a child must identify a specific grapheme from others and add sound to it (known as grapheme – phoneme correspondence). Dyslexics have difficulty identifying phonemes and are therefore unable to orientate themselves with respects to grapheme – phoneme correspondence, and with their deformed phonological key they are not able to access meaning which is coded within the graphic representation of words.

Eye movements of the so-called phonological dyslexics (see Rayner, 1998, 2009) are highly erratic but only while reading a text adequate to their chronological age. When reading a much easier text, their eye movements become renormalised. In non-reading tasks, i.e. those not requiring linguistic processing, their eye movements do not significantly differ from the controls. The cause for the failure among linguistically oriented dyslexics to read correctly then does not originate from incorrect eye movements but from imperfect linguistic or phonological processing instead.

Visual dyslexics are quite different to phonological dyslexics. Visual dyslexia is associated with the theory of visual deficit or magnocellular theory (Eden, Stein, Wood, & Wood, 1994; Eden, Van Meter, Rumsey, & Zeffiro, 1996; Galaburda, Menard, & Rosen, 1994; Livingstone, Rosen, Drislane, & Galaburda, 1991; Ray, Fowler, & Stein, 2005; Stein, 1991, 2001; Stein & Fowler, 1984; Stein, Richardson, & Fowler, 2000; Stein & Talcott, 1999; Wilmer, Richardson, Chen, & Stein, 2004). Advocates of the theory of visual deficit argue that the nature of the problems dyslexics have need not necessarily be of linguistic origin, as problems may also occur in a non-verbal situation.

Presumably, the problems are accountable to changes in the magnocellular system. Proponents of the visual and magnocellular theory ascribe significance to differences in eye movements between dyslexics and control groups while performing non-verbal tasks. They claim that the eye movements of dyslexics are normal but they are unable to process visual images and spatial information as such. Supposedly, eye movements are not the cause of poor reading. The theory of visual deficit does not deny the validity of phonological problems. The above mentioned authors (e.g., Eden et al., 1994; Ray, Fowler, & Stein, 2005, etc.)

merely try to demonstrate the fact that dyslexia is a far more diverse problem than generally believed and that the problems of dyslexics reach beyond the limits of traditionally-defined language deficits stemming from impaired phoneme awareness.

A specific approach to the eye movements of dyslexics is expressed in the cerebellar theory. Its proponents note that many dyslexics have, in addition to the reading and language problems described in the phonological theory, non-linguistic problems, such as imbalance or motor and sensorimotor discoordination (Brookes & Stirling, 2005; Finch, Nicolson, & Fawcett, 2002; Nicolson & Fawcett, 2011; Nicolson, Fawcett, & Dean, 2001; Reynolds, Nicolson, & Hambly, 2003; Stoodley, Fawcett, Nicolson, & Stein, 2006). The cerebellum plays a significant role in controlling oculomotor behaviour – i.e., cerebellar dysfunction manifests itself through eye movements and affects a person's reading aptitude.

The share of visual-spatial problems among dyslexics remains an unanswered question. Under the strong influence of phonological theory, it was generally believed that the language-deficit type was more prevalent, whereby visual or visuo-spatial disorders were considered complementary. Researchers estimated that at least two thirds of dyslexics have had problems with the phonological conversion of orthographic symbols (Rayner & Pollatsek, 1989; Castles & Coltheart, 1993). However, this was conclusion was challenged by the visual theory followed by the magnocellular theory. Stein (2001) pointed out that in his studies only one third of dyslexics have mostly phonological problems, one third mostly visual-orthographic problems, and in the remaining third both types of problems are more or less equally prevalent.

Despite a great number of studies focusing on links between eye movements, reading and dyslexia, published in the last three decades, the role of eye movements is still unclear. The aim of this study, therefore, is to help clarify the role that eye movements play in reading and/or dyslexia.

In one of our studies (Jost, 1992), we came across the case of a boy who had above average phoneme awareness, yet below average reading development. This case is the subject of the following study.

METHOD

Participants

The boy was part of a sample group of cca 100 children which we observed from preschool age to the end of sixth grade. The aim of the study was to determine to what extent eye movements could be used to predict reading development. All the children had attended kindergarten from the age of 5 to 6 and had then started to attend primary school (children in the Czech Republic start school in September after they reach the age of six).

All the children had an identical curriculum and were subjected to identical teaching methods. The children's native language was Czech. None of the children's families were registered with the social support system on suspicion of the child abuse and neglect syndrome (CAN), alcoholism, any form of addiction, criminal behaviour or financial poverty.

During the five-year monitoring, none of the children underwent any neurological or psychiatric treatment. None were assessed as ill by a paediatrician. No sensory defects were detected from among the children, that is to say, visual defects had been amended.

EYE MOVEMENTS

We used an infrared head mounted eye tracker developed by Pavlidis at the University of Thessalonike, Greece. Eye movements were measured with 100 Hz temporal and 0.2° spatial resolution. The recordings were monocular (taken from the left eye only). The reason for this was the need to simplify the apparatus. The device was not able to register vergence; nevertheless, the recordings of saccades were not affected in any significant way.

Despite that the subjects perceived the tasks binocularly. The child was seated in a chair and his/her head was stabilised by a chin and/or head rest. The eye tracker was calibrated using a three-point routine. The output data were subjected to an online check that enabled the subject to be encouraged continuously to perform to the best of his oculomotor ability. Fixations and saccades interrupted by blinks were excluded from further analysis.

We used two non-reading tasks to examine eye movements:

1) In the so-called sequential task, the child watched a horizontal row of six lights which lit up gradually from left to right and back, right to left, etc. This task stimulated horizontal saccades.

2) The child fixed its vision on a target drawn on a piece of paper. This task tested fixation stability.

MEASURES

In the preschool period we gained information from parents about the personal and family history of their child, and from kindergarten teachers we gained information about the hyperactivity of the child using the shortened version of Connors' Rating Scale.

In the primary school period we recorded the child's successes, administered tests on reading, intelligence (WISC), graphomotorics, attention, sociometric position, self-concept and Connors' Rating Scale for hyperactivity and examined speech with regard to articulation dyspraxia.

Reading
This was measured by a standardised test and described by the amount of correctly read words within a time interval. Speed of reading in the Czech linguistic environment (i.e., in a phonetically highly consistent spelling system) correlates with comprehension (Matejcek, 1998a, 1998b). The reading test was administered at the end of the 1st, 2nd, 3rd and 5th grades. The purpose was to describe the development of the children's reading. What usually occurs (Bakker, 1990) is that within the first two years of school attendance (the phase of initial reading), children preferentially process text using the right cerebral hemisphere. Between second and third grade, they switch to the left hemisphere and begin to use this one preferentially. In fourth or fifth grade, reading development should be stabilised (the phase of advanced reading). Average pupils in Czech schools are able to read fluently and with comprehension any unknown text in their native language adequate to their age after the first term of school attendance.

Graphomotorics
This is measured using a standardised test (Matejcek & Strnadova, 1974). The child copies geometric shapes according to those supplied, e.g. circle, diamond, the intersection of a five-pointed star and a pentagon, etc.

Pupil's self-perception
Measured by SPAS (Student's Perception of Ability Scale) from Boersma and Chapman (Matejcek & Vagnerova, 1987). This test measures overall level of self-appraisal and enables the comparison of a pupil's self-appraisal in the subjects of Czech language (i.e. native language) vs. mathematics.

Visual concentration
This is measured using a standardised test (Jirasek, 1975) during which the child is presented with a table containing randomly arranged numbers from 1 to 25

and the child's task is to find the numbers in sequential order as quickly as possible. The task is repeated ten times and the time is measured each time.

Pupil's popularity
This is measured by the pupil's score on the sociometric test L-J from Long and Jones (Musil, 1977) using a like-dislike scale.

RESULTS

EYE MOVEMENTS

Figure 1 shows the characteristic course of the boy's eye movements at preschool age (6 years, 7 months).

It is evident from the report that the child fixates each light and adheres to the required sequence. With regards to this characteristic alone, the child's eye movements are within normal limits. A striking feature of eye movements which stand out from the norm is dysmetria, which means an imbalance between the size of an eye movement and the movement of its stimulus. Dysmetria takes the form of hypermetria or hypometria. During hypermetria, or 'overshooting', the eye movement is greater than the movement of the stimulus from one position to the other; the eye must return in order to reach the correct position – this is known as a corrective regressive saccade (Ciuffreda & Tannen, 1995; Leigh & Zee, 1987). In Figure 1 we can see hypermetric saccades *a, c*, and *i* (saccades *b, d*, and *j* are regressive corrections). During hypometria, or 'undershooting' (Ciuffreda & Tannen, 1995; Leigh & Zee, 1987), it is reversed; the saccadic movement is shorter and the subsequent correction is progressive. In Figure 1 we can see hypometric saccade *e* (*f* is a progressive correction). Dysmetria is a reflection of the precision of saccades. In a pathological context, dysmetria may signify a cerebellar disorder, possibly a disorder of the brain stem, or a sign of a visual disorder, e.g. hemianopia. Dysmetria is also studied in relation to reading disorders (Ciuffreda & Tannen, 1995; Leigh & Zee, 1987).

In our boy's case, the overall percentage of dysmetric saccades was equal to 20.7% and the percentage of overshoots was 18.5% out of the overall number of saccades. In terms of z-score, this represents a value of 2.77 which is well above average. The boy´s eye movements were significantly hypermetric. The above average proportion of dysmetria induced an increased variability in eye movements during fixation which we expressed using a variation coefficient (V = standard deviation during fixation / average time of fixation). Its value was equal to 42%.

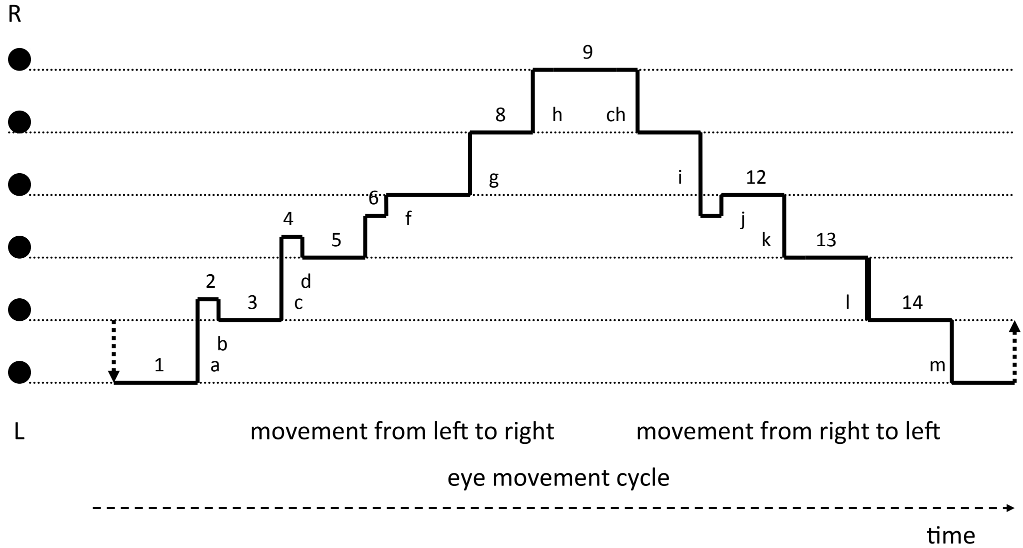

Figure 1. Eye movements of the observed child in the sequential task. Numerals signify fixations (horizontal lines), lower-case letters signify saccades (vertical lines). The capital letters 'L' and 'R' indicate left and right edges of the row. Lights were turned on and off gradually from left to right and back, from right to left, etc. As one light was turned on, the previous light was switched off. The light period was constant and lasted for 0.5 seconds. The distance between lights was an angle of approx. 3°.

The boy's eye movements were characterised by *regular fixations* as well as *auxiliary fixa*tions which induce greater variability in fixation times (both terms, regular fixations and auxiliary fixations, are working terms). We identified auxiliary fixations as those which followed dysmetric saccades and then led to regular fixations. In Figure 1 auxiliary fixations are numbered 2, 4, 6 and 11. All other fixations in Figure 1 are regular. We did not observe any *chaotic fixations* (working term) during which one or more stimuli (lights) would have escaped the child's attention and seriously undermined the sequence of eye movements and introduced chaos.

To express the temporal stability of eye movements, we split each recording in half and compared the two halves. An entire recording lasted approximately 40 seconds so each half was 20 seconds long. Although at first glance this may seem like a short period of time, this approach has proved itself in preschool children. The boy's performance was characterised by a decrease in oculomotoric efficiency. If, in the first half of examinations, he overshot at a rate of 15% out of the overall number of saccades, which is typical for boys, then in the other half it was over 18%.

To express right-left orientation, we distinguished between the direction of left to right and right to left, see Figure 1. In the boy's case, dysmetric saccades were oriented unevenly from right-left: from left to right we observed about 16% dysmetria while in the opposite direction, from right to left, it was only 4.3%.

In the second oculomotoric task, the fixation of a stationary point, we observed a good performance. The boy managed to eliminate eye movements and kept his eyes in one position. Therefore, we were able to exclude fixation instability.

PSYCHOLOGICAL VARIABLES

Phonological awareness

At preschool age the child was able to break apart and assemble words according to individual speech sounds, even with respect to their correct order in words. He was also able to break apart and assemble words using syllables with respect to their order in words. He was able to correctly identify the initial, middle and end sounds in words including vowels. He was able to correctly identify words that rhyme and was able to actively construct a rhyme to a particular word. He was able to correctly identify alliteration which is the repetition of a particular sound at the beginning of a series of different words and/or phrases. According to such findings, uncomplicated reading development of the child was predicted.

Personal history

We found no significant factors. The mother's pregnancy was without complications, the baby was carried to full term, there were no perinatal incidents, the child's birth weight was 3,000g / 50cm, postnatal development was normal, the child was not examined neurologically, underwent common childhood illnesses, there was no serious illness. There were no sensory defects.

School history

The child began attending primary school on schedule and without delay (children begin school at the age of six in the Czech Republic). The child did not repeat any school year and did not change schools or attend specialised classes. The child was observed from the mid-80s – at that time there was a single kind of primary school with a single common programme for all children. Reading was taught via an analytic-synthetic method.

Family history

The family was complete, functional. The father was a university student, teacher; the mother was a high school student. The family spoke Czech, both parents had

Czech nationality. The child had an older sister who flourished with excellent results in linguistic and non-linguistic subjects.

Success

An average grade was calculated from marks in a final report covering grades 1-6 inclusively. The average grade for both Czech (native) language and mathematics was 2.00. In the Czech Republic, a classification system of 1-5 is used where 1 represents the best performance and 5 the worst.

Intelligence

In the WISC test, the child's verbal performance outweighed non-verbal (verbal IQ = 113, performance IQ = 101).

Reading

At the end of first grade, the boy was able to read 20 words/min., i.e. the verbal IQ – reading discrepancy equalled 1.80 SD. The percentage of errors was 4.8%. At the end of second grade, the boy was able to read 33 words/min., i.e. the verbal IQ – reading discrepancy equalled 1.87 SD. The percentage of errors was 5.7% which is on the borderline of sten 4 and 5. At the end of third grade, the boy was able to read 47 words/min., i.e. the verbal IQ – reading discrepancy equalled 2.13 SD. The percentage of errors was 5.1%.

At the end of fifth grade, the boy was able to read 67 words/min., i.e. his verbal IQ – reading discrepancy equalled 1.73 SD. The percentage of errors was 2.9%, i.e. on the borderline of sten 4 and 5. Reading comprehension was satisfactory, storyline context was clear to him, and he reproduced substantial parts of the plot. However, he needed lead-in questions. When reading he complained of visual wobble (letters blur, move and hurt his eyes).

Reading pace acceleration

Reading pace acceleration (*Ac*) was expressed by the formula *Ac* = the number of correctly read words in the second minute / the number of correctly read words in the first minute (%). Acceleration is a parameter with which we evaluate the uniformity of reading performance. A significant decrease in Ac can be ascribed to, e.g. increased fatigue which may in turn be caused by a weakened CNS. At the end of second grade (after two years of schooling), the result of the reading test was *Ac* = 83, i.e. a decrease in reading tempo which within the reference sample of children (N = 85) was average (z = 0.03). At the end of third grade (after three years of schooling), the value was Ac = 52 which corresponded to the value z = -2.23, i.e. well below average.

Concentration

The child's performance corresponded to sten 5 (weak average zone). Pace acceleration corresponded to sten 5 (weak average zone).

Graphomotorics

The child's performance was found to be in sten 5 (weak average zone).

Speech

The child's speech from preschool age was fluent and articulate with no lisp. The child expressed his ideas very well. During second grade, we examined the child's clumsy articulation / speech dyspraxia with negative findings. But even in this respect, his language developed very well.

Self-perception

We administered the SPAS test during fifth grade. The overall result corresponded to sten 5 (weak average zone). Following are the results of each subtest: general skills (sten 6), confidence (sten 6), mathematics (sten 5), reading (sten 5), spelling (sten 3-4), writing (sten 8).

Hyperactivity

Connors' Rating Scale of hyperactivity was administered to teachers during the child's preschool years and a second time during grade three. In both cases the child was assessed as being very calm and focused.

Sociometry

During third grade we gave the children the L-J questionnaire which measures social rank by popularity–unpopularity. The test showed a slightly increased popularity index and ruled out unpopularity.

Findings after 18 years. The same child's eye movements were examined after a period of 18 years, at the age of 23, using the same method as in his preschool years. At the time, the boy had graduated from secondary vocational school. After finishing primary school, he had initially enrolled at high school but had transferred to vocational school during his first year of study. He did not enjoy reading and tended to avoid reading. If he reached for a book, it was usually comics. When reading he complained of visual wobble (letters blur, move and hurt his eyes) and headache. He was able to read 70 – 80 words/min; his rate of reading was decelerated. Reading comprehension was satisfactory, he reproduced substantial parts of the text, however, without details.

A recording of eye movements showed similar characteristics as were present when he was of preschool age: extensive dysmetria and subsequent corrective saccades, without chaotic fixations.

DISCUSSION

Eye movements in the monitored subject showed long-term stability, i.e. continuous dysmetric saccades with the exclusion of fixation instability.

This finding corresponded with the following psychological findings: the structure of intellectual performance was less uniform; verbal performance outweighed non-verbal performance in the child. This dominance could be interpreted as being due to an over-stimulating family environment (father: university student/ teacher, mother: high school student), but when taking into account eye movements, reading development and even some findings in attention tests and drawing tests, it is more probable that the cause was neurobiological.
The findings in attention tests and drawing tests were non-pathological and without defects, however, the child's performance was within the range of average, or rather, weaker average. In contrast, the child's potential level of development was higher as can be inferred by his performance in the verbal part of the intelligence test (above average).

Attention test and graphomotoric test performances both correspond to findings in the non-verbal part of the intelligence test which was also within the range of average. Reading development was generally slower in relation to the norm. Even after primary school, reading probably played a serious role in the further educational development of the child. The child had intellectual needs, applied to a high school which he left within the first year to attend a less challenging vocational school – the child should be seen as a 'less demanding reader'. We saw a noticeable decline in reading pace which, when taking into account the child's weak performance in the non-verbal part of the IQ test and the pace distribution in the attention test, supported the possibility that the child was easily fatigued.

The attention test indicated performance was in the lower part of the average range and acceleration rate was also reduced. In reading, in non-verbal subtests of the IQ test and even in the attention test, the child worked in a visual environment in which he had to orientate himself. Similar requirements were placed on him during the oculomotor task. The child had problems in all these tasks, his performance was delayed intraindividually – in relation to his developmental level as estimated by the IQ test, or interindividually in comparison with his peers.

These findings contrast strikingly with the high level of phonological skills observed in preschool age. It is precisely this above average level of phonological skills together with above average performance in verbal parts of the IQ test and a stimulating family environment that led us to believe that the reading development of the child would be smooth and at least average. This conclusion was fully consistent with the phonological theory of dyslexia.

However, reading development did not confirm this hypothesis. It was probably not a case of deep dyslexia. We may consider the child´s reading difficulties to have been objective, not caused by the child himself or his family or school. The most probable cause were CNS peculiarities of a prolonged nature, These peculiarities included the child’s reduced ability to orientate himself in a visual environment in which a subject must process different visual forms and be able to manipulate them, putting them into sequences or syntaxes and finding relationships and regularities between them.

The boy’s problems could have escalated if the boy had lived in a linguistic environment which was characterised by non-transparent orthography. Non-transparent orthography is particular to the English environment where spoken and written forms of language differ greatly. The Czech language, with its transparent orthography, probably offered the boy more favourable circumstances for reading development despite his deficit of non-phonological nature (see also analogous experiences from the field of the German language, Wimmer & Schurz, 2010).

The child is unlikely to have ADHD. The child was calm and focused throughout kindergarten and primary school. In oculomotor behaviour, we observed good fixation stability. Findings in personal history were negative. Motor coordination problems were not observed. Speech was pure and without clumsy articulation.

In our case study, long-term partial weakening of eye movements (dysmetria) coincided with long-term partial weakening of reading skills at decoding level. It was difficult to determine whether this was a case of comorbidity or a close relationship. If it was a close relationship, dysmetric eye movements were probably not induced by poor reading and poor linguistic processing of text. Eye movements of preschoolers were tested using non-reading tasks, where the influence of language was absent. Eye movements were also tested in the period before the commencement of reading education. It was possible to judge from the results that eye movements were not the only factor controlling reading ability and were probably not the dominant factor.

A causal relationship between eye movements and reading was found to be improbable. The findings in this study suggest there is a common factor affecting eye movements and reading ability. It could be an imbalance within the central nervous system, as referred to by Bakker (Bakker, 1990; Bakker, Van Strien, & Licht, 2007). This imbalance could be reflected in eye movements. Bakker’s Balance Model is based on the specialised functions of each brain hemisphere:

the visual processing of text is largely the function of the right hemisphere while the allocation of meaning to graphemes is largely the function of the left hemisphere.

The model assumes that the foundation of dyslexia is disrupted co-operation between the two brain hemispheres: the perceptual type is characterised by the tendency to process information in the right hemisphere. This type is able to decode graphemes quite well but has difficulty in assigning them meaning. Reading is slow with few mistakes. In contrast, the linguistic type is characterised by a disruption to the visuospatial factor.

Reading is characterised by substantive errors (the reordering of letters and syllables, omission of speech segments and syllables, the addition of words and their distortion) and in relation to decoding, this type has a greater ability to understand what is read. Both types of dyslexia were examined oculomotorically (Donders & Van der Vlugt, 1984). Eye movements of the perceptual type were characterised by a greater number of fixations, short saccades and a low number of regressions. In contrast, eye movements of the linguistic type were characterised by a large variation in fixation times and a large number of regressions. Our case study resembled the linguistic type from a reading and oculomotoric point of view.

Reading is a multifactor skill in which eye movements are one of many influences. Based on our case study it was not possible to compare the influence of eye movements of preschoolers on reading development with the influence of phonological awareness and family environment. If dysmetric eye movements had at least a hypothetically adverse effect on reading development in our case, then this effect was probably compensated in part by good phonological awareness and a linguistically stimulating and literacy-rich family environment.

CONCLUSION

The case report showed that long-term, partial weakening of eye movements correlated with long-term, partial weakening of reading development. With caution it can be stated that examinations of eye movements may contribute to prognostic considerations in the field of reading development and may become part of preschool screening.

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