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Research Article

# Computer Based Oculomotor Training Improves Reading Abilities in Dyslexic Children: Results from A Pilot Study

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## Abstract

Poor written-language skills in dyslexia is often lifelong and impairs academic results. A lot of uncertainty still surrounds the question of the appropriate methods of diagnosis and treatment. The purpose of the present study is to validate the hypothesis of a computer-based program for remediation of reading deficits in dyslexic children. The program described in this study consists in four different exercises (rapid naming task, Stroop task, motion perception and saccades) performed fifteen min a day, five days a week, for eight weeks. Sixteen dyslexic Italian children (mean age: 10.2 ± 0.3 years) participated to the study. Reading abilities were tested before and after the oculomotor training by eye movement recordings. Ten over sixteen children significantly reduced reading time and thirteen over sixteen significantly reduced fixation time. These training benefits suggest that a computer - based oculomotor program could be an easy and practical tool for improving reading performance in dyslexic children. Program limitations and future directions are discussed.

### Highlights

- Home computer-based oculomotor training improves dyslexic children's reading performance.
- Reading capabilities improvement in dyslexic children by computer-based oculomotor training could be due to visuo-attentional processes controlling eye movements and words comprehension.

**Keywords:** Dyslexia; Fixations; Oculomotor training; Reading; Saccades; Visuo-attentional mechanisms

## Introduction

Dyslexia is a specific learning difficulty in decoding letters or in reading accuracy and fluency. Between 5 and 15% of the school-age population is affected, depending on how the disability is defined and on the transparency of the language [1]. The origin of dyslexia is complex, involving genetic and environmental factors [2], and despite intensive research on the subject, its etiology is still unknown.

Even if the hypothesis of a phonological deficit in dyslexia has been suggested by several authors [3,4,5], many studies propose that beyond phonology a more general dysfunction, which affects auditory and visual perception, motor and attentional skills [6,7,8,9] can be found. Furthermore, in dyslexic subjects' fMRI studies provided an objective measure of abnormal processing of visual motion, especially in the extrastriate middle temporal (MT) brain areas, which have been identified as motion sensitive, [10-11,12] supporting the hypothesis of an M-cell pathway visual abnormality in subjects with reading deficits.

Reading is a complex cognitive process involving several mechanisms (visual perception, eye movements -saccades and fixations, semantic/linguistic abilities). Our and other groups reported a number of oculomotor deficiencies during reading task in dyslexic children. Palvidis [13] was the first to observe that Greek dyslexic children had a longer and an increased number of fixations, shorter amplitudes saccades, more backward saccades, suggesting that such abnormalities could be responsible of slowness reading abilities in dyslexic children.

Rayner [14] reported as well a poor saccade performance in the reading of English dyslexic children. Among Italian dyslexic children, De Luca et al [15] observed longer and increased number of fixations during the reading. In German dyslexic children Trauzettel-Klosinskiet al. [16] showed a relationship between the slower reading speed and a greater number of saccades; Li et al. [17] highlighted similar oculomotor deficiencies in a Chinese dyslexic population. Our group [18,19,20] reported atypical oculomotor patterns in French dyslexic children, suggesting a deficiency in the visual attentional processing as well as an immaturity of the oculomotor saccade and vergence interaction leading to poor motor control of the two eyes during reading. Actually, it is not yet clear whether atypical eye movements performance is the cause or the consequence of reading difficulties in dyslexia; however, our driven hypothesis is that given the immaturity of cortical areas involved in the triggering and performing eye movements in dyslexic children, they could benefit from oculomotor training for improving reading capabilities.

In the literature, a small number of studies performing oculomotor training in dyslexia are described. Rounds et al. [21] reported that in ten 'poor readers' adults the number of regressive saccades and the number of fixations improved following a 12 hours oculomotor training (doing saccades). Solan et al. [22] correlated the effect of the oculomotor training (by using PAVE, Perceptual Accuracy-Visual Efficiency program) with the effect of a comprehension training (requiring children to provide the correct missing word(s) in a sentence) in a group of fifteen dyslexic children. They reported that the number of fixations as well as the number of regressive saccades were improved by reading oculomotor training and resulted in a significant improvement in comprehension; similar results were obtained by comprehension training, supporting the notion of a cognitive link between visual attention, oculomotor performance and reading comprehension.

The present study aims to assess the effect of a computer-based oculomotor training on Italian dyslexic children's reading performance. Based on the results of the present pilot study, our final purpose is to develop a new functional training program for dyslexic children.

## Materials and Methods

Participants Sixteen dyslexic children (mean age: 10.2 ± 0.3 years) were recruited by the Centro Leonardo in Genoa. Inclusion criteria were scores which were more or equal than two standard deviations from the mean, and a normal mean intelligence quotient (IQ, evaluated using the WISC-IV), namely between 85 and 115. Also visual acuity was normal for all children tested (≥20/20 in both eyes). For each child a neuropsychological and phonological assessment was performed. Reading time was measured, general text comprehension, and ability to read words and pseudo-words using the battery DDE2 [23] were evaluated.

Reading abilities were tested by using the MT test [24] at inclusion day and 8 weeks after computer based oculomotor training. Table 1 summarizes the clinical profile of children tested, with the chronological and reading age and the number of syllables read par second measured before and two months after the training. Note that the clinical improvement index after training is of 0.6 syllables/sec par school year, which is equal to 0.05 syllables/sec / month. Given that the training lasted 2 months, a significant improvement in reading syllables was equal to 0.1 syllables/sec [25]. The investigation adhered to the principles of the Declaration of Helsinki and was approved by the Institutional Human Experimentation Committee.

### Reading Text

Text was presented on a 22″ LCD screen with "full HD resolution" (image size of 1920x1080 pixels) and the refresh rate was 60 Hz, sufficient to ensure a normal saccade performance [26].

Child was asked to read a text of four lines from a children's book ("Il grande gigante gentile" of Roald Dahl). The paragraph contained 40 words and 174 characters. The text was 29° wide and 6.4° high; mean character width was 0.5° and the text was written in black ''courier'' font on a white background. Participants were asked to read the text silently, and to raise a finger at the end of the reading in order to stop the eye recording. The experimenter was questioning the child at the end of the task to verify that he/she read the text and understood it.

This reading task (using a different text with similar words characteristics) was recorded before and 8 weeks after the computerized oculomotor training.

### Eye Movement Recording

During the execution of reading task, eye movements were recorded using an Eye Brain T2® (SuriCog) head-mounted eye tracker. This eye tracker is a medical EC certified device. The accuracy of this system is 0.25°, and its recording frequency reaches 300 Hz. This device can record the position of the eyes horizontally and vertically, independently and simultaneously for each eye.

Calibration is done before eye movements recording. The calibration consists of a succession of red dots (diameter of 0.5°), presented on a flat PC screen of dimensions 512 x 288 mm, corresponding to the nominal diagonal size of 22''. During this procedure, we asked the children to gaze a grid of 13 points mapping the screen at a distance of 58 cm. The respective positions for each point in degrees in the horizontal / vertical plane were: 20.9° /12.2°; 0° /12.2°; 20.9° /12.2°; -10.8° /6.2°; 10.8° /6.2°;

-20.9° /0°; 0° /0°; 20.9° /0°; -10.8° /-6.2°; 10.8° /-6.2°; -20.9° /-12.2°; 0° /-12.2° and 20.9° /-12.2°. Calibration is calculated for a 250 ms fixation period for each point. There is no obstruction of the visual field during registration with the recording system and the calibrated zone covers a visual angle of ± 22° [27]. After the calibration procedure, the reading tasks were explained to the child. Duration of each task varied accordingly to the specific participant' reading speed.

## Computerized Oculomotor Training

The training consisted in four different exercises done for 15 minutes per day for 5/7 days per week for 8 weeks. In order to maximizing training effect, each exercise was composed of 8 levels with increased difficulty and were developed using the Unity game engine (Unity Technologies).

**Rapid automatized naming:** Stimuli were 20 random 5-letters strings (e.g., R H S D M) built up from various symbols (uppercase and lowercase letters, numbers and punctuation marks). Symbols were presented in black on a white background using the Arial text font with a varying size from 20 to 100. At the start of each trial, a blank screen was presented for 500 ms. A letter string was then displayed at the centre of the screen for a period of between 1 and 0.3 sec. Thereafter, child has to click on the good answer among five proposals. As the level increases, the number of symbols increases, the size of symbols was reduced as well as time symbols displaying on the screen (from 1s for level 1 to 250 ms for level 8).

**Motion detection:** the motion stimulus consisted of 420 yellow dots (10 pixels each) presented on a black background. Dots were placed at random positions on the all screen, and were either stationary or moved coherently rightwards or leftwards within this virtual square. Each trial began with a blank screen for 400 ms, after which stimuli appeared. Task included two sets of 80 trials with "motion" and "no motion" trials appearing randomly in equal probabilities (40 trials each). Stimuli motion speed (in pixel/frame) and time before motion were reduced as levels were increased.

**Stroop tests:** words and conflict-words or stimulus conflict-words and color patches were randomly used. In the first case the task required the children to read the written color names of the words independently of the color of the ink (for example, they would have to read "purple" no matter what the color of the font). In second case, children were required to say the ink-color of the letters independently of the written word with the second kind of stimulus and also name the color of the patches. If the word "purple" was written in red font, child would have to say "red", rather than "purple". When the squares were shown, the participant spoke the name of the color. The number of words was increased according to level difficulty (from 1 to 3) and displayed words time was reduced (from 1s for level 1 to 300 ms for level 8).

**Saccades to the right similarly to those done during reading a text:** A horizontal array of dots and cross were presented in equal probabilities on each trial was displayed during a varying period from 1 to 0.15 sec. The distance between stimuli varying randomly from 2 to 60% of the screen. The number of crosses was half number of dots for each level. This exercise was designed to require horizontal saccades from stimulus to stimulus, but did not contain any linguistic content. Child was instructed to press the left mouse click every time a cross appears on the screen. Time each stimulus was displayed was reduced according to level difficulty (from 1s for level 1 to 250 ms for level 8). Note that the difficulty of each of these tasks increased when the child performed correctly 90% of the task.

## Data Analysis

Calibration factors for each eye were determined from the eye positions during the calibration procedure. The software MeyeAnalysis (provided with the eye tracker, SuriCog) was used to extract saccadic eye movements from the data. It automatically determines the onset and the end of each saccade by using a built-in saccade detection algorithm. The algorithm used to detect saccades was adapted from Nyström and Holmqvist. [28] All saccades with amplitude greater than 2 degrees were detected. The algorithm searches for velocity peaks by identifying samples where the velocity is larger than a velocity threshold ($\Theta > \Theta_{PT}$). The iterative algorithm is given an initial peak velocity detection threshold $PT_1$, which could be in the range of 100° to 300°/sec, but the choice is not critical as long as there are saccades with peak velocities reaching this threshold. For all samples with velocities lower than $PT_1$, the average (μ) and SD (σ) are calculated. The threshold is updated as $PTn=\mu_{n-1}+6\sigma_{n-1}$ for each iteration. For each detected saccade peak the algorithm searches backward (from the leftmost peak saccade sample) and forward (from the rightmost peak saccade sample) in time for the saccade onset and offset. Saccade onset is defined as the first sample that goes below the saccade onset threshold and where $\Theta_i - \Theta_{i+1} \geq 0$. Saccade offset is defined as the first sample that goes below the saccade offset threshold and where $\Theta_i - \Theta_{i+1} \leq 0$. All detected saccades were verified graphically by the investigator and corrected/discarded if onset and/or offset were not clearly automatically marked. See for details other studies made by our group [18, 27]. We analyzed all prosaccades (from left to right) and backward saccades (from right to left). Oblique, backward saccades made to start a new line were excluded from the analysis.

For reading task the number and the amplitude of saccades or prosaccades, the number of backward saccades, the duration of fixation and the total duration of the reading task were calculated. Statistical analysis was performed by the Student t-test. The effect of a factor is deemed significant when the p-value is below 0.05.

## Results

Figure 1 shows the percentage of correct response during the four types of training for each child. The different colors indicate the different difficulty of each exercise (from the easier, level 1 to the most difficult, level 6). The majority of children performed quite well the training; four children were not able to reach level 6 for motion detection and saccades exercise (C1, C6, C10, C14 and C1, C9, C10, C14, respectively) while three children (C1, C10, C14) did not reach level 6 of the Stroop exercise; on the contrary, the majority of children (12/16) did not reach level 6 of the RAN exercise (C1, C4, C5, C6, C7, C8, C9, C10, C11, C13, C14, C15).

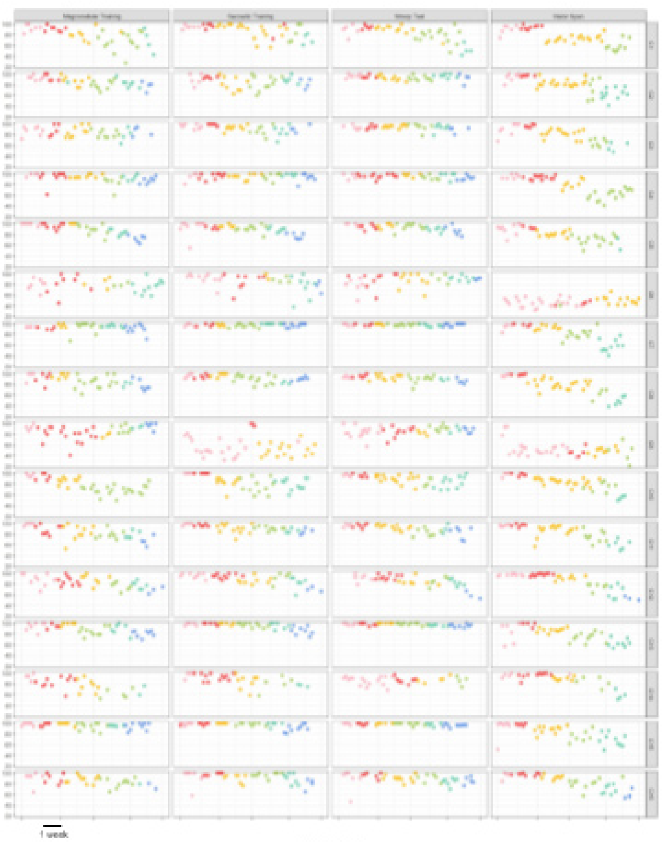


Figure 1

**Figure 1:** Percentage of correct response during the four types of training for each child. The different colors indicate the different difficulty of each exercise (from the easer, level 1 to the more difficult, level 6.

As shown in Table 1 for the majority of dyslexic children (11/16) the number of syllables read par second significantly improved after training.

| Subjects Chronological age (yrs) | Reading age (yrs) | Syll/sec Pre-training | Syll/sec Post-training |
|---|---|---|---|
| C1 (7.8) | 6 | 0.93 | 0.89 |
| C2 (8.8) | 6.5 | 0.7 | 1.33 |
| C3 (8.9) | 6.7 | 1.95 | 2 |
| C4 (9) | 7 | 1.12 | 1.42 |
| C5 (9.2) | 7 | 0.77 | 1.54 |
| C6 (9.7) | 7 | 1.21 | 1.19 |
| C7 (9.8) | 7.5 | 2.21 | 2.56 |
| C8 (10) | 7.8 | 1.68 | 1.64 |
| C9 (10.2) | 7.8 | 1.67 | 1.67 |
| C10 (10.3) | 7.9 | 1.71 | 1.93 |
| C11 (11.2) | 7.9 | 1.83 | 2.21 |
| C12 (11.3) | 8 | 2.28 | 2.74 |
| C13 (11.3) | 8 | 2.22 | 2.65 |
| C14 (11.3) | 8 | 3.13 | 2.92 |
| C15 (11.5) | 7.8 | 1.92 | 2.11 |
| C16 (12.7) | 8.5 | 2.88 | 3.05 |

**Table 1:** Clinical characteristic of children tested. Bold number indicates significant improvement of the number of syllables read par seconds.

Figure 2 shows the total duration of reading task (A) and the duration of the reading task (B) before and after training. The total duration of the reading task, for the majority of children (except C3, C9, C12 and C14) decreased after training and the Student t-test reported a significant change after training ($t = 2.37$, $p < 0.03$); similarly, the duration of fixation decreased for all but three children (C3, C10 and C14) and the Student t-test showed a significant decrease after training ($t = 2.76$, $p < 0.01$).

A)

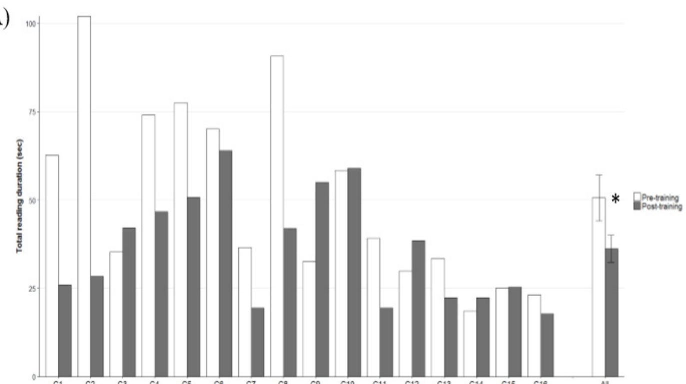


**Figure 2:** Total duration of reading task (A) and duration of fixations for all dyslexic children before and after training. Vertical bars indicate the standard error. Asterisks indicate that the value is significantly different ($p < 0.05$).

The number and the amplitude of pro and backward saccades as shown in Table 2 did not change after training.

| | Number of prosaccades | Amplitude of prosaccades (deg) | Number of backward saccades | Amplitude of backward saccades (deg) |
|---|---|---|---|---|
| Pre-training | 36 ± 9 | 3.3 ± 3.2 | 10 ± 4 | 3.5 ± 3.0 |
| Post-training | 38 ± 9 | 3.3 ± 3.9 | 10 ± 4 | 3.1 ± 3.5 |

**Table 2:** Mean number and amplitude of pro and backward saccades (± their standard error) before and after training.

## Discussion

The results of the present pilot study confirm the hypothesis that computer based oculomotor training improves reading capabilities in dyslexic children. This can be easily objectively shown by using an eye tracker, able to identify and register oculomotor patterns changes while reading. These findings are discussed below.

In the computer based oculomotor training proposed in the present study, children improved saccades capabilities, visuo-attentional capacities as well magnocellular abilities. We suggest that all these mechanisms occur because visuo-attention and saccades are strictly linked [29] and that the magnocellular visual pathway is also involved in oculomotor tasks [30]. Note that even if the origin of dyslexia is still unknown, the hypothesis of visuo-attentional mechanism deficit for the etiology of dyslexia has been already proposed by several researchers. For instance, Bosse et al. [31] reported visual-attention (VA) span deficit in dyslexia, suggesting that VA span deficit might contribute to dyslexia, independently of the presence of a phonological disorder. Interestingly the same group [32] applied VA span training for six days/week, during three consecutive weeks and they showed that after training a dyslexic girl of 9 years old improved significantly her reading abilities. Post training fMRI assessment showed increased activation of the bilateral superior parietal lobes. This study, even if is limited to one subject only and needs obviously further exploration, showed that a VA span training not only changed reading skills but also increased brain activity in the superior parietal cortex known to be responsible of VA span abilities. We could make the hypothesis that the RAN training used in our study may improve VA span, leading to reading improvement, similar to Valdois's finding. On the other side, it is well known that magnocellular system is deficient in dyslexia [33, 34] and a study from Chouake et al. [35] explored the effect on reading capabilities of a magnocellular training in thirty-five young non dyslexic subjects. The training consisted in a motion detection task done during five consecutive days and reading abilities were measured before and after training using a lexical decision task. These authors showed that magnocellular training improved speed of lexical decision and accuracy in anagram and words recognition. This is in line with the study from Cornelissen et al. [36] suggesting that the magnocellular system plays an important role for shifting visual attention on words during reading task. The training of saccades and Stroop exercises facilitate the control of selective attention and inhibitory functions and flexibility; all these processes are strictly linked to cognitive capabilities need to understand the text.

Finally, taken together all these findings suggest that oculomotor training could improve visuo-attentional capabilities in dyslexic children leading to a better reading performance, and allowing better and faster word identification. Note that the novelty of the present study is also that eye movement performances during reading were recorded in order to acquire precise and objective information on post - training oculomotor patterns changes, that is actually missed in the previously cited studies [32, 35].

Another important point to be discussed is the individual home training performance follow up. Indeed, this is the first time that a training done at home is controlled and supervised, and user performance continuous monitor is an important step to develop in a training program. Indeed, by looking the Figure 1 we can follow the assiduity of the training done by each child and the absence of shortening in the total duration of reading task and/or in the duration of fixations, particularly for child C3 and C14 could be due to the fact they did not performed well all different levels of all exercises. Further research on such issue will be necessary to confirm these previous findings; however, a computerized oculomotor training could be helpful for improving reading capabilities in dyslexic children.

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