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Neurovisual training (TRIGRAM) in young patients with visual-perceptive dyslexia

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Abstract

Dyslexia is a language-based learning disability. Although this condition is characterized by anatomical malformation of the brain, it seems that the typical reading pattern of dyslexic may be also related to more complex sensory deficits. Among them, visual-perceptive deficits have been described in a subtype of dyslexia, called visual-perceptive dyslexia. The distinctive feature of a patient suffering from visual-perceptive dyslexia form is marked by effortlessly recognize the characteristics of each individual stimulus.
The Tetra protocol is a visual-perceptual evaluation protocol that was introduced for the diagnostic phase and the rehabilitation of visual-perceptive dyslexia. The diagnostic tests include: the eidomorphometry test, designed to evaluate the perception of spatial relationships; the contrast sensitivity threshold test, especially at low spatial frequencies; and the REPORT TEST words, to assess the speed and the reading efficiency. In addition, the rehabilitation phase is carried out with the visual neuro-enhancement program TRIGRAM, a visual training proposal designed to reduce the lateral masking phenomenon in visual-perceptive dyslexic.
Thus, in this study we used the diagnostic tests of TETRA® Protocol to determine presence of visual-perceptual abnormalities in children with dyslexia. Proven time the presence of these visual-perceptual alterations, the patients were also subjected to the rehabilitation sessions of TRIGRAM, in order to investigate whether this visual training may improve the pattern of reading. At the end of the program (t1) and after three months (t2), the same subjects underwent the same diagnostic tests of TETRA® Protocol to evaluate and confirm the results obtained during rehabilitation program.
The results showed a significant increase in contrast sensitivity at low and high spatial frequencies. Moreover, the same improvements in the visual system's ability to discriminate the contours of an object within the field of view, have been maintained three months after the end of treatment. We also observed a significant improvement in the perception of spatial relationships, with reduction of SRA value.
In conclusion, this study demonstrates that the visual rehabilitation training (TRIGRAM) is able to improve the perception of spatial relationships, and increase contrast sensitivity in young patients affected by "visual dyslexia". Nonetheless, these data need to be confirmed in larger cohort of subjects in order to establish whether these effects can also increase lexical ability (increased reading speed and reduce errors during the lexical task).

Keywords: *Dyslexia; visual-perceptive; protocol TETRA; Neurovisual training; TRIGRAM; children.*

Introduction

Dyslexia is a specific learning disability which prevents people affected, although intellectually normal, to automate and then to make smooth the reading [1]. It is estimated that 3-20% of school-age children is dyslexic, with a higher incidence in males (from 3: 2 to 5: 4) [2].
In the past years, anatomical abnormalities in the brain of dyslexic patients have been described. Different cortical malformations mainly distributed in the frontal region and in the left language area were documented, including ectopy (small neuronal clusters in abnormal cortical layers), and dysplasia (loss organization structural feature of cortical neurons), especially in adjacent areas [3].

Despite these efforts, these results, while having considerable theoretical interest, however, are not able to explain the typical reading pattern of dyslexic. It is likely that there are different subtypes of dyslexia and for this reason beyond the anatomical and pathological brain changes, it is reasonable to assume that the basis of dyslexia lies a more or less complex sensory deficits [4.

In recent years numerous studies have been carried out with the intent to understand what, if any, correlation between dyslexia and vision [5,6]. In this regard there are two completely opposing theories have been formulated: (a) the visual-perceptive theory with dissociation between visual acuity resolution and lexical performance [7]; (b) the phonological theory: following a defect in sensitivity to auditory frequency modulation, there would be a deficit in the representation of the phoneme; that is why the dyslexic would be in difficulty in processing subtle differences between similar phonemes from acoustic point of view (Pronunciation deficit) [8]. Therefore, according to these theories, there would be, alongside a phonological form (dysphonetic dyslexia), another form of dyslexia (visual-perceptive), a shape defined by Castles and Coltheart [9] "surface dyslexia".

The distinctive feature of a patient suffering from visual-perceptive dyslexia form is marked by effortlessly recognize the characteristics of each individual stimulus (eg letters), for both distance and for near, but fails in a clear manner to read as we would expect [10].

With the attempt to provide a useful tool to investigate the relationship between dyslexia and vision, the tetra Protocol was introduced 15 years ago by the ophthalmologist Charles Aleci. The Tetra protocol is a visual-perceptual evaluation protocol useful in the diagnostic phase and the rehabilitation of dyslexia [11].

The protocol TETRA®, the Diag version & Rehab, consists of diagnostic tests adapted to detect the presence of visual-perceptual alterations in the patient dyslexic, and a visual neuro enhancement program to strengthen the magnocellular system, which in the patient "dyslexic vision "is highly deficient. The diagnostic tests include: the eidomorphometry test, designed to evaluate the perception of spatial relationships; the contrast sensitivity threshold test, especially at low spatial frequencies; and the REPORT TEST words, to assess the speed and the reading efficiency [12]. The visual neuro-enhancement program is the TRIGRAM, which is a visual training proposal designed to reduce the lateral masking phenomenon [13].

Thus, in this study we used the diagnostic tests of TETRA® Protocol to determine presence of visual-perceptual abnormalities in children with dyslexia such as to define the same dyslexic patients as "dyslexic VISUAL ". Proven time the presence of these visual-perceptual alterations and changes in the efficiency and speed of reading (REPORT TEST), the patients were also subjected to the rehabilitation sessions of TRIGRAM, in order to investigate whether this visual training may improve the pattern of reading. At the end of the program (t1) and after three months (t2), the same subjects underwent the same diagnostic tests of TETRA® Protocol to evaluate and confirm the results obtained during rehabilitation program.

Materials and methods

Patients

In this study enrolled 28 children (16 males and 12 females) diagnosed with dyslexia, aged 6 to 17 years, were initially enrolled. Of them, only 11 (4 females and 7 males, mean age 11.5 years) met the criteria for inclusion in the rehabilitation training program (TRIGRAM) (**Table 1**).

Table 1. Demographic characteristics of the total subjects and of 11 subjects included in the study.

	Before inclusion	Included in the study
Number of subjects	28	11
Mean Age (years)	10.82±3.42	10.72±3.34
Sex	16 M/12 F	7 M/4 F

M=male; F=female

The subjects enrolled were selected at the Centre for Low Vision Clinic of Ophthalmology of the Policlinico Umberto I in Rome.

All patients, after reading and signing the information and informed consent from parents, underwent to quantification of visual acuity, a full orthoptic assessment of corneal reflexes, cover tests, ocular motility, objective convergence and evaluation of the stereoscopic effect (Lang II).

The presence of a contemporary speech therapy (4 of 10 subjects have made, in conjunction with our training, sessions by speech therapist) did not influence patient recruitment. The study adhered to the declaration of Helsinki. The local ethic committee approved the study.

Inclusion criteria

The inclusion criteria for enrollment of subjects in the study included: (a) certain diagnosis of dyslexia; (b) subjects over the age of six years, in order to assess the lexical pattern (although the word TEST REPORT was prepared for subjects who attend at least the third grade school level); (c) subjects with esotropia/exotropia with visual acuity 10/10.

Exclusion criteria

Subjects suffering from photosensitive epilepsy were excluded from the study because the conditions of repeated thachistoscopic stimulation could trigger a seizure. Patients with esotropia/exotropia, and/or eye or general pathologies which negatively influence visual acuity were also excluded from the study.

Tetra protocol

At the end of orthoptic evaluation, each young patient, after being instructed on the exam mode (explained in an understandable manner and appropriate to the age) underwent to the spatial relations test (eidomorphometry), then to the sensitivity contrast test, and finally to the REPORT TEST words.

Eidomorphometry

To perform the eidomorphometry test, the patient was placed at a distance of 70 cm from a tablet placed on a lectern that would guarantee a standard condition for the examination. At all projected stimulus the patient should report if the latter was a vertical, horizontal ellipse or circle. Having to do with children, the term "ellipse" was substituted with the synonym of "lying egg" or "egg standing" and circle, to differentiate the projected stimuli recognized by the subject. Each answer was recorded on the tablet examiner operator. Taking into account the learning phenomenon, the test was repeated twice in order to enable children to become familiar with it.

At the end of the test, the software generated a graph in which the position of the spot at the coordinate axes and the eccentricity of the ellipse respectively represented the degree of alteration in perception spatial relationships and the level of anisotropy. The value of index anisotropy (SRA) was used as comparison parameter between t 0 (pre-treatment) and t1 (post-treatment).

Contrast Sensitivity Test

After eidomorphometry test, the contrast sensitivity test was performed. The tablet was placed 2m away from the subject, always leaning on a special lectern. This is a psychophysical test with a not forced threefold choice, targeted to estimate the threshold to the lowest spatial frequencies, namely 0.5, 0.75, 1.5 and 3 cycles per degree. The contrast function is also enhanced by measuring at 6 and 12 cycles per degree. The coupling to a psychophysical algorithm type STAIRCASE 4-2-1 makes the test quicker, allowing the subject to complete the exam in less than 3 minutes. In this test the patient was asked to understand if the inclination of the projected bars (when perceived) was right, left or vertically. Each answer was marked by the examiner on the operator tablet.

At the end of the examination, the software showed a contrast sensitivity curve placed within a Cartesian plane having on the ordinate axis the contrast sensitivity threshold values and on the abscissa the values of the spatial frequencies expressed in cycles per degree. The contrast sensitivity values expressed by the letters A-B-C-D-E-F (for the various spatial frequencies tested) were used for statistics.

At the end of the two tests, the presence of visual-perceptive alterations supported the hypothesis that some of the patients already diagnosed for dyslexia were also "visual dyslexic", since the tests showed the presence of alterations in the perception spatial relationships and in contrast sensitivity. These subjects were the patient's "type" required in our study and therefore were subjected to the REPORT TEST words.

REPORT TEST words

These patients were positioned in front of the tablet to the read distance and were asked, without seeking the best performance, to read aloud the words presented in binocular vision. The program then determined, for each presentation, the reading speed and the number of errors made. When completed the reading of the first set of words, a new sequence was administered, in order to obtain two measurements for each value of anisotropy. Then a software with automatic and integrated statistical analysis elaborated the results, providing an overall judgment on the degree of visual-perceptual patient involvement.

The parameters used in the statistical analysis were: the confidence interval of the reading speed (CRR) in syllables per second medium and its maximum and minimum; and the number of errors made during the lexical task.

Visual Training TRIGRAM

At the end of the evaluation through the TETRA® Protocol diagnostic tests, 11 subjects were enrolled to the experimental study, only those identified as "visual dyslexic". In agreement with the parents, we opted for a meeting a week during which one rehabilitation session of Visual Training trigram would be carried out. The rehabilitation phase lasted a total of ten weeks.

Each meeting lasted an average of twenty minutes, during which the child, placed in front of the "tablet" to a distance of 40 cm, was asked to recognize the 120 trigrams (three-letter groups) presented with different eccentricity values to the right and left of the target fixation.

After treatment, each subject enrolled in the study, was again subjected to diagnostic tests carried out in the pre-rehabilitation phase (t1) (eidomorphometry, contrast sensitivity, and REPORT TEST words).The goal was to evidence at the end of the visual training: (a) the improvement of lexical performance, in terms of speed and accuracy of reading, through statistical analysis; (b) highlight that, through the reinforcement of visual-perceptual skills, perceptual abilities of spatial relationships and the ability to recognize the contours of an object placed within the field of view were increased.

In order to assess whether the results obtained were maintained over time, at a distance of three months (t2) after the completion of rehabilitation sessions, all patients were retested at the TETRA® Protocol diagnostic tests.

Statistical analysis

Statistical analysis, for each index analyzed, was performed with the Wilcoxon signed-rank test for paired samples, a nonparametric test whose null hypothesis involves comparison between medians of quantitative variables. The level of significance chosen was alpha = 0.05.

Results

Tetra Protocol

Eidomorphometry

For the statistical analysis of the perception of spatial relationships, the SRA value (the anisotropy index) at time t0 (pre-treatment) and at time t1 (post-treatment) has been utilized.

The SRA quantifies the level of alteration of perception of spatial relationships. The higher the SRA value the more is high the anisotropy of the visual system. Specifically, with an SRA value> 0 it is observed an anisotropy of the vertical type. Conversely, in the case of an SRA <0 we will have anisotropy of horizontal type. A SRA value equal to 0 determines the absence of anisotropy, that is, the isotropy. The indicative value of SRA in normal reading schoolchildren subjects is less than +/- 4%.

The average value of the SRA at time t0 of the 11 subjects was 7.6. Among the subjects enrolled at t0, only 2 (20%) presented horizontal anisotropy with SRA = - 4; one subject (10%) presented a condition of isotropy with SRA = 0, while the remaining 8 (80%) instead presented a vertical anisotropy with a mean SRA value of 9 (SRAmax= 19).

At the end of visual training (t1) the average SRA value decreased from 7.6 to 2.7 (**Fig. 1**) Wilcoxon signed-rank test evidenced a significant improvement in the perception of spatial relationships post-treatment (p-value = 0.007). Furthermore, of the 11 subjects enrolled, seven (70%) returned in a normal range with SRA between +/- 4%. It is also noteworthy that the maximum SRA value decreased from 19 at t0 to 9 at t1.

As already mentioned, three months after the end of treatment (t2), all patients were re-submitted to eidomorphometry test to compare the median SRA values at t1 and t2. Wilcoxon signed-rank test for paired samples showed no significant differences between the time points (p=0.38) indicating that the improvement obtained was maintained over time.

Contrast sensitivity

For the statistical analysis of the contrast sensitivity, the numerical values expressing the ability of the visual system to discriminate the contours of an object placed within the visual field were used.

These values are indicative of such sensitivity to different spatial frequencies, expressed in cycles per degree: A = 0.5 cycles per degree; B = 0.75 cycles per degree; C = 1.5 cycles per degree; D = 3 cycles per degree; E = 6 cycles per degree; F = 12 cycles per degree.

As shown in **Figure 2**, the out-put graph, having on ordinate axis the contrast sensitivity and on the abscissa the spatial frequency, enables us to immediately highlight, through a color scale (red: deficits, green: no deficit), the possible reduction in contrast sensitivity to the respective spatial frequencies.

We found that at time t0 the median values, for each spatial frequency were the following: A = 18.50; B = 32.50; C = 152.00; D = 196.00; E = 134.00 ; F=104.50. As expected, these values indicated that a deficit in contrast sensitivity at lower spatial frequencies (0.5 and 0.75 cycles per degree) was present, sustaining the "deficit of magnocelullar system theory " typical of the visual dyslexics.

At the end of visual training, it was observed a clear increase in contrast sensitivity at particular spatial frequencies. The mean increase in contrast sensitivity at different spatial frequencies, after 10 rehabilitation sessions, is shown in **Figure 3**.

The improvement was confirmed by the Wilcoxon signed-rank test results with the sign for paired samples. In details, we found a statistically significant result with the following frequencies: A= 0.5 cycles per degree (p = 0.011); B= 0.75 cycles per degree (p = 0.005); E= 6 cycles per degree (p = 0.005); and F= 12 cycles per degree (p = 0.046).

As for eidomorphometry, each subject enrolled was again subjected to the contrast sensitivity test three months (t2) from the end of treatment. Wilcoxon signed-rank test showed no significant difference between the contrast sensitivity, at time t1 and at time t2, to the different spatial frequencies.

REPORT TEST words (accuracy and reading speed)

For the statistical analysis of the lexical task different parameters have been taken into account.

The purpose was to highlight if, at the end of the TRIGRAM visual training, together with an increase in contrast sensitivity and a reduction in SRA values, there was also a significant improvement in the efficiency and speed of reading.

The following parameters were used: (1) CRR (Cumulative reading rate): the reading speed in syllables per second for each tested interval divided by the number of intervals tested (average reading speed in syllables per second). We used the CRR average value, and the upper (CRRsup) and lower (CRRinf) limits, delimiting the confidence interval. (2) Errors: number of read errors made during the TEST REPORT words.

CRR

The average reading speed at t0 and t1 are shown in **Figure 4**. As shown in the figure, no significant increase in reading speed in syllables per second was found. This is also confirmed by the p values obtained with Wilcoxon signed-rank test. In addition, we did not find significant differences in reading speed between t1 and t2.

Errors

The graph shown in **Figure 5** presents the average number of errors made in the sample in the pre and post-treatment. We found that the average of the errors committed in t1 (2.10) is lower than the average of the errors committed at t0 (3.33). Nevertheless, the application of the non-parametric test does not show a statistical significance. Moreover, we also found no significant differences in the number of errors between t1 and t2.

Discussion

The first aim of this study was to verify the presence of an alteration in the perception of spatial relationships and contrast sensitivity, especially at low spatial frequencies, in patients who had already been diagnosed with dyslexia. Once made eidomorphometry and contrast sensitivity tests, patients considered suitable for enrollment were submitted to the TEST REPORT words. The second goal was to learn about the specific features of the lexical task, in terms of speed and accuracy, and identify any possible improvement at the end of the visual training TRIGRAM.

As reported in a previous study of Aleci [11], in our study we observed the presence of these visual-perceptual alterations in dyslexic patients probably responsible for the typical pattern of reading. Differently from the study of Aleci in 2015 [13] where visual training was administered once a day for 2 weeks, our protocol contemplated a single visual session per week. In addition, the protocol used in the study of Aleci required a follow-up two weeks after the end of treatment. Instead in our study the diagnostic test battery TETRA® was re-administered to the patients three months later (t2) by the end of visual training. The goal was to highlight the real improvement of the lexical performance at the end of the treatment and its maintenance over time. Certainly, in addition to improving the lexical performance of the enrolled subjects, even a reinforcement of the visual-perceptual capacities was expected: increased contrast sensitivity at low spatial frequencies and improved perception of spatial relationships with anisotropy reduction.

The results showed a significant increase in contrast sensitivity at low and high spatial frequencies. Moreover, the same improvements in the visual system's ability to discriminate the contours of an object within the field of view, have been maintained three months after the end of treatment. We also observed a significant improvement in the perception of spatial relationships, with reduction of SRA value. The anisotropy index at the end of treatment was reduced, thus improving the perception of spatial relationships of the enrolled subjects. On the opposite, statistical analysis on the reading speed did not show a statistical significance, although the reading speed values, in syllables per second, were lower than those obtained at the end of the rehabilitation sessions. Similarly, the number of errors made during the lexical task at t1 is lower than at t0, but not at a significant level (p = 0.205).

The efficacy of rehabilitation training through the TRIGRAM protocol has already been observed and described in the study of Aleci [13]. It was found that TRIGRAM, administered to 14 children aged between 8 and 11 years old, was effective to improve the lexical task.

Specifically, an increase in the reading speed of 11.8%, expressed in syllables per second, was recorded at the REPORT TEST words. The inability to obtain statistically significant values in the analysis of the speed and accuracy of reading in our study is probably due to the limitations in patient recruitment. Thus, our study, although meticulous and accurate, may have produced different results from that of Aleci because of a reduced number of subjects recruited. For purely practical reasons and for the reduced amount of families willing to participate in this experimental study, we were forced to enlist individuals of different age (ranging from six to seventeen years). This implies that the pattern and the reading speed of the older subjects, for biological and physiological reasons, are distinctly different from that of the younger subjects and, therefore, difficult to be included into a single statistical analysis. This problem would be overcome by a far greater sample size, in order to obtain significant results on the reading speed. The ideal procedure would be to subdivide a larger sample group into age groups (6-8; 8-11; 11-14; 14-17) in order to also highlight the efficacy of treatment in patients with different biological age.

In conclusion, this study demonstrates that the visual rehabilitation training (TRIGRAM) is able to improve the perception of spatial relationships, and increase contrast sensitivity in young patients affected by "visual dyslexia". Nonetheless, these data need to be confirmed in larger cohort of subjects in order to establish whether these effects can also increase lexical ability (increased reading speed and reduce errors during the lexical task).

Figure 1. The mean value of the SRA in the pre (t0) and post-treatment (t1) of the 11 subjects included in the study.

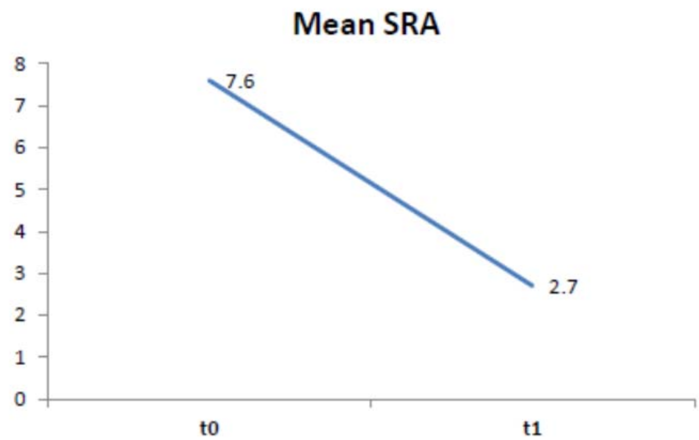


Figure 2. Example of out-put graph, having on ordinate axis the contrast sensitivity and on the abscissa the spatial frequency (cycles per degree). The possible reduction in contrast sensitivity to the respective spatial frequencies is highlighted through a color scale (red: deficits, green: no deficit).

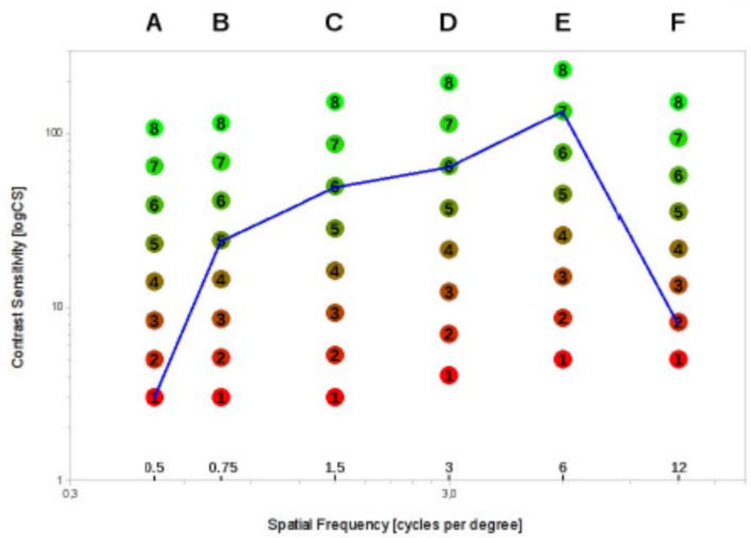


Figure 3. The mean increase in contrast sensitivity at different spatial frequencies, after 10 rehabilitation sessions with TRIGRAM in the pre (t0) and post-treatment (t1).

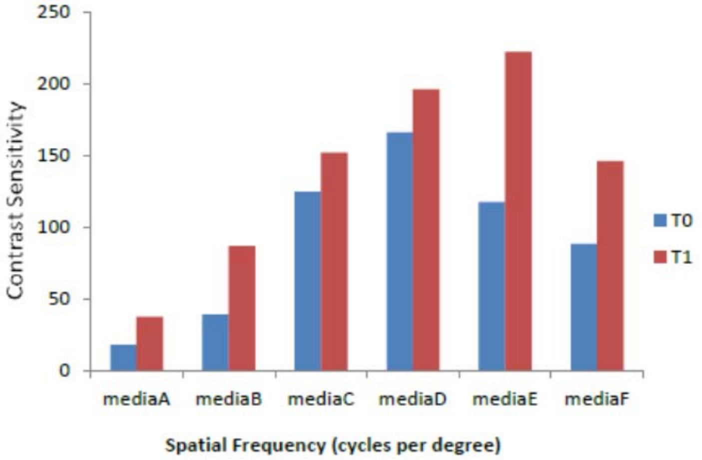


Figure 4. The mean, minimum and maximum reading speed in the pre (t0) and post-treatment (t1)of the 11 subjects included in the study.

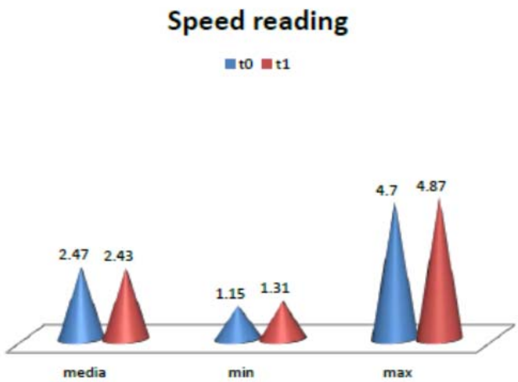
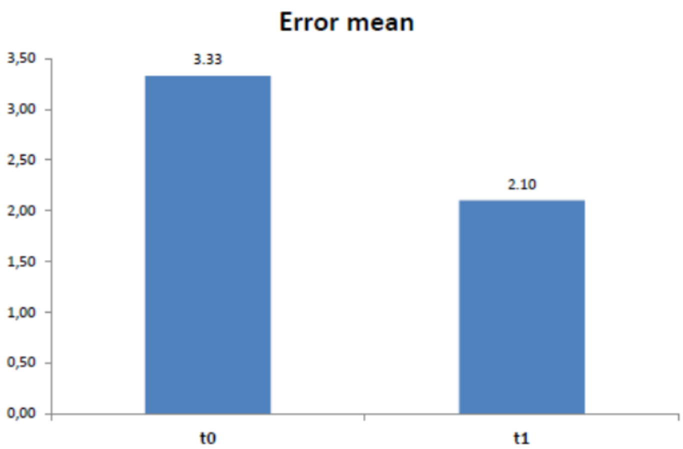


Figure 5. The mean number of errors made in the pre (t0) and post-treatment (t1).



References

1. Hulme C, Snowling MJ. Reading disorders and dyslexia. Curr Opin Pediatr. 2016 Dec;28(6):731-735.
2. Snowling MJ, Melby-Lervåg M. Oral language deficits in familial dyslexia: A meta-analysis and review. Psychol Bull. 2016 May;142(5):498-545.
3. Krishnan S, Watkins KE, Bishop DV. Neurobiological Basis of Language Learning Difficulties. Trends Cogn Sci. 2016 Sep;20(9):701-14.
4. Ramus F. Developmental dyslexia: specific phonological deficit or general sensorimotor dysfunction? Curr Opin Neurobiol. 2003 Apr;13(2):212-8.
5. Stein J. Dyslexia: the Role of Vision and Visual Attention. Curr Dev Disord Rep. 2014;1(4):267-280.
6. Gori S, Facoetti A. How the visual aspects can be crucial in reading acquisition? The intriguing case of crowding and developmental dyslexia. J Vis. 2015 Jan 14;15(1):15.1.8.
7. Ortiz R, Estévez A, Muñetón M, Domínguez C. Visual and auditory perception in preschool children at risk for dyslexia. Res Dev Disabil. 2014 Nov;35(11):2673-80.
8. Law JM, Vandermosten M, Ghesquiere P, Wouters J. The relationship of phonological ability, speech perception, and auditory perception in adults with dyslexia. Front Hum Neurosci. 2014 Jul 2;8:482.
9. Castles A, Coltheart M. Varieties of developmental dyslexia.Cognition. 1993 May;47(2):149-80.
10. Araújo S, Pacheco A, Faísca L, Petersson KM, Reis A. Visual rapid naming and phonological abilities: different subtypes in dyslexic children. Int J Psychol. 2010 Dec 1;45(6):443-52.
11. Aleci C, Piana G, Piccoli M, Bertolini M. Developmental dyslexia and spatial relationship perception. Cortex. 2012 Apr;48(4):466-76.
12. Aleci C, Piana G, Anselmino F. Evaluation of spatial anisotropy by curvature analysis of elliptical targets. Open Ophthalmol J. 2010 May 31;4:15-21.
13. Aleci C, Belcastro E, Canavese L. Visual Training Helps Improve Reading in Dyslexic Children with Abnormal Crowding. An International Journal, 2015; 3:85-94.