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Figure identification in dyslexia: An eye-tracking study

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Abstract

This study presents an eye-tracking investigation of dyslexic subjects in comparison with good readers in a figure visualization task. Pairs of identical and different items presented in horizontal or vertical spatial orientation, using continuous or discontinuous lines were presented to subjects. The results revealed that dyslexics fixed target areas less often and were slower than good readers in all conditions. When figures were different, the dyslexic group presented higher fixation latencies in the horizontal conditions than the control group. When figures were equal, the dyslexic group displayed greater fixation times in the discontinuous conditions than in the continuous conditions.

Keywords: dyslexia, eye tracking, visual processing, perception of figures

Introduction

Reading requires an ability to distinguish between words and images. Even though the same brain areas are activated both for image and writing visualization, these two kinds of stimuli have different properties in cognition. According to Dehaene (2012), the reading of words and letters requires a neuronal recycling which allows readers to establish differences between the recognition of visual invariances in the visualization of objects, which usually can be recognized, no matter what the angle of presentation may be. Therefore, a cup is a cup, whether its handle is to right or to the left. Even if the cup is upside-down, the handle is still recognized as a handle, and the cup as a cup. In contrast, letter b is different from letter d merely because of the spatial orientation of each letter. The brain processes the image applying principles of parallelism and hierarchy, recomposing the image in a hierarchical pyramid of neurons, as an electronic microprocessor. This is a very fast and efficient process which is developed in an average of 150ms both for word and for object recognition (Dehaene & Cohen, 2007, Kolinsky & Fernandes, 2014).

Tanaka (2003) used electrodes to monitor neuronal activity in monkeys as they observed images. The study found t a mosaic of neuronal detectors in the lower temporal cortex, representing the elementary shapes of the images, enabling the monkeys to recognize the physical description of the objects. These elementary shapes which were named as “proto-letters” seem to play an important role in figure as well as in letter processing. Tanaka and associates established the set of elementary shapes which allowed them to reconstruct a neuronal map for the whole image, even in the presence of variants. This process explains the variability of forms, which are recognized in different contexts and functions (e.g. a beach chair, an office chair, a wooden chair a plastic chair are all variations of a basic chair). This principle of invariance also plays a role in face recognition (the face of a young person and the face of an old person), and in letter recognition, as well. Letters also seem to be processed according to this same principle. It seems very likely that the shape of the letters was primarily used in the decoding of visual scenes. For instance, the shape of the letter T often appears in different scenes, such as the branches of a tree or the lines in the square angles of a cube. These shapes are part of Mankind's visual experience and are, therefore, acceptable icons for the brain.

These shapes are frequent and invariant and the eyes can be fixated on them, searching this invariance. The deletion of these shapes in angles and vortices might disturb figure recognition. Biederman (1987) develops a full-fledged theory to explain how the human visual perception is supported by nonaccidental properties such as vortices and invariant shapes in object recognition. The process would apply in the recognition of letters as well, such as in P/p/p.

It is possible that visual recognition is favored by these shapes and that there is also a relation between the shapes and letter recognition, as they seem to have been internalized along the species evolutionary process and are now pre-connected in the visual system which is used both in shape recognition and in letter recognition in reading. Shape recognition is an advantage in identification and in interaction with the environment, and learning new shapes is a sophisticate evolution of the cortex, which has adapted as a result of a requirement of human culture which developed reading. Therefore, reading can be understood as a development of cultural pression in human evolution. At school age, the brain of the human children is, therefore, adapted and ready to use the combinatory principles of images and associative functions which is required in the learning of reading. It is still necessary, however, to expose the children to new visual stimuli and teach them how the writing characters cams vary in form and in relation to sounds, (cf. Cagliari & Cagliari, 1999; Dehaene, 2012; Scliar-Cabral, 2010, 2015).

We have been discussing the typical development of reading in normal children up to this point. However, what is this process like in atypical situations? Dyslexic children often display difficulties in visual processing from the very beginning, failing in basic skills of association and mirror figure recognition or even in the recognition of subtle differences between two shapes. These difficulties have an impact on their abilities to recognize letters and decode words in reading. Accordingly, dyslexia has been described as a specific learning disorder with direct impact on reading. According to the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, of the American Psychiatric Association, dyslexia is confirmed based on criteria as those we have been discussing in this paper.

Therefore the investigation of the visual properties of figure recognition and of reading is fully justified. Dyslexia displays disorders in character recognition, entailing unnecessary cognitive effort and disturbing comprehension. In this paper, psycholinguistic eye-tracker experiments investigating the visual processing of images are presented in order to advance the discussion about visual recognition in dyslexia. The refinement of the research in this area, using visual fixation times in millisecond, in addition to accuracy rates, in the recognition of differences and similarities between members of pairs of figures, comparing systematically the performance of good readers and dyslexic children may bring progress for the diagnosis and treatment of the disorder, which is thought to affect 10% of the population.

The specific objective of this research project were to identify differences in figure recognition in the vertical and horizontal axis and when angles are deleted. Another objective was to identify patterns of ocular fixation in figures which are similar to letters, comparing good readers and dyslexic children. Dyslexic children have been observed to change letters which are similar in a vertical or in a horizontal axis p/d/q/b, t/f/, l/i, m/n, for example) and also to mirror letters and numbers. Our eye-tracker experiment uses figures which are similar to the ones used in the standardized Reversal Test, but collecting subtle visual fixation and saccadic measures in order to try to answer questions such as: (i) are there differences in visual perception along the horizontal and vertical axis? (ii) are there differences in the visual inspection of figures in which there is deletion in the angles as compared to complete figures? (iii) are there differences between the dyslexic and the control groups?

In order to try to answer such questions, it is hypothesized that dyslexic children would take longer than the control group to process different pairs of figures than their similar counterparts and that they would be less accurate in the perception of differences in the horizontal and vertical axis, as they usually mix up letters which differ in this respect. The next section will describe the experiment in detail.

Method

The experimental method was used in this study, which made use of the eye-tracking technique. A Tobii TX300 eye-tracker equipment was used in the Experimental Psycholinguistic Laboratory of the Federal University of Rio de Janeiro (LAPEX-UFRJ). Eye-tracking is a direct inspection methodology which allows the observation of visual processes as they unfold on-line. The two most important measures used in the study were the visual fixation durations and the progressive and regressive saccadic movement patterns. As discussed in Maia (2015), the technique provides on-line direct measures of visual inspection and has been productively used in Psycholinguistics for decades to investigate visual cognition processes, helping in the development of models of language and image processing.

The independent variables of the experiment were the figure characteristics (within subjects) and the two groups of participants (between subjects). The variable figures characteristics varied in terms of the following factors: vertical (V), horizontal (H), different (D), continuity (C), discontinuity (D). These characteristics were observed in the two groups, dyslexic and control. The dependent variables were the fixation durations and the accuracy rates in the detection of differences or equalities between the pairs in each group.

Participants

30 children (15 diagnosed as dyslexic and 15 identified as good readers) were eye-tracked. They ranged in age between 7 to 14 years old and they were registered as students in public and private schools of Rio de Janeiro in grades from first to fourth. The dyslexic children were diagnosed by a multidisciplinary team of the ELO Project (UFRJ), under the auspices of Institute ABCD (iABCD). Children who presented comorbidities were excluded from the group. The research project was submitted to the Institutional Review Board of the Ethics Committee of the Neurology Institute Deolindo Couto (CEP/INDC), having been approved in process number 009/2010).

The children in the control group were students in Escola Municipal Tenente João, located on the Federal University of Rio de Janeiro campus, on Fundão Island. The research project was submitted and approved by the City of Rio de Janeiro Education Board (Process number 07/001803/2015, published in Rio de Janeiro DO on July 16, 2015 p. 61). For the inclusion of children in the control group, we initially used the indication criteria of the teachers, who rated them as good students and readers. We also screened children using an assessment of expressive language and oral reading speed test. The evaluation of expressive language was the Brandão & Spinillo (2001), which proposes five levels of complexity of understanding and expression of oral narratives. In this test, children must retell a story and answer interpretation questions that check their understanding. Afterwards, children are required to tell a story from a picture. It is expected that in the fifth level, children can produce complex plots, articulating facts following a guiding principle through which problems are solved. Usually, at this level, an ability to establish causal relationships and inference of facts is observed. A level V ability is expected in children from the literacy class. All children in the control group had level V for comprehension and expression of narratives, and those that did not obtain this score were discarded. Informally, during the production of narratives, it was observed if there were phonetic or phonological failures in the child's speech. If it was positive, the child was excluded from the research group, in order to make sure that children did not present difficulties in oral language use. For the evaluation of reading speed, a stopwatch measure was used to check the velocity of reading as children read a text. Children should not present reading failures, and should reach the standard speed recorded by

Mousinho & Correa in Rio de Janeiro (Mousinho & Correa, 2013) and present 100% understanding of the reading material, which was checked by means of interpretation questions. Children who did not meet these standards were excluded from the research group.

Materials

The materials used were made up by 56 items (pairs of different figures), 7 from each condition, namely, vertical, horizontal, and different. To balance the stimuli, pairs of similar figures were used, 7 with solid lines touching the vertices and 21 identical pairs in which the vertices did not touch. The figures were arranged to occupy similar areas and have the same sizes, controlling extraneous variables. Stimuli were randomized manually (pseudo-randomized). The figures were copied from a test widely used for visual perception, known as the Reversal Test, developed by Ake W. Edfeldt Stockholm in 1955. In the experiment presented here, the intention was to use the same figures (not all) to observe the visual behavior of the children, using the eyetracker for the on-line measurement.

The Reversal Test is also known as test of reversed figures, precisely because it was intended to provide observations of visual perception at the level of spatial relationships in children who are candidates to begin the process of learning to read and write (Mora, 2006); Lourenço, 2012). Ake W. Edfeldt Stocholm is a Swedish psychologist and professor emeritus in education of reading mechanisms. The test is widely used in clinical practice to this day and is designed to check the visual maturity for reading and can be applied by teachers or health professionals in order to complement diagnosis. Normally the application is performed individually, but it can also be applied in groups of ten children. (Mora, 2006; Lourenço, 2012).

The experiment reported in the present paper was based on the Reversal Test, but unlike the traditional application of this test, the eye-tracking technique allowed us to collect on-line measures. Our design decisions of including similar pairs of figures, in addition to the different pairs intended to establish comparisons with another eye-tracking experiment using letters, which took as reference the study described in Kolinsky & Fernandes (2014) and the studies reported by Dehaene (2012), which follow the reading neuronal recycling theory.

Procedures

The experiment was assembled and run in a Tobii TX 300Hz equipment. For the collection of data of the target group, the Lapex / UFRJ room was used. For the control group, the equipment was moved to the school that is located on the UFRJ campus, on Fundão Island. The procedure began with the instrument calibration, followed by a practice test to familiarize the child with the activity, before submitting the child to the actual testing. Each child was asked to keep their eye gaze on the computer screen, looking at two figures which appear together on the screen. The task was simply to visually scan the pictures and decide whether they were equal or not. In order to register their decision, they should push a button marked on the computer keyboard in yellow, so as to bring up another screen containing two words YES / NO. If the images were completely equal, they should look at the word YES, if not, they should look at the word NO. They were instructed to continue this procedure until the end of the test. If the child was slow to press the button to change the screen, the screen would change by itself, following a 5 second timeout. Examples of stimuli follow below.

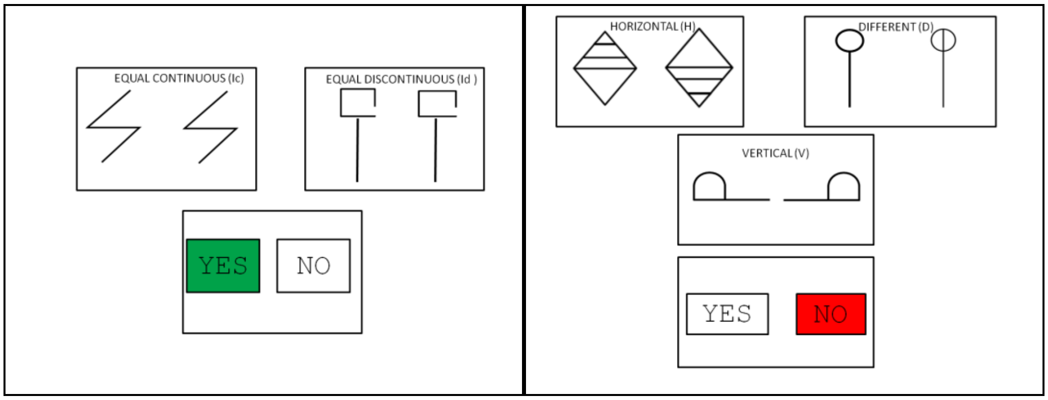

Figure 1. Examples of figures used in the experiment. Source: Personal files

Data analysis

Data were analyzed in two steps by observing the average reaction time in the on-line measures and the accuracy rates for differentiation and equality of the figures (off-line measure). The vertex points of the figures were specifically established as areas of interest for analyses, as this area has been usually taken as cognitive reference, as evidenced by several researchers. Thus, the area considered for analysis of fixation durations was the area of the vertices of the figures. The first fixation durations were analyzed in each characteristic, in the defined area. . For data analysis, we used the statistical program ezANOVA .

Results

On-line measures

The average first fixation durations on the vertex of the figures were computed, as indicated in the table below:

Table 1. Average first fixation durations in the vertex of figures in milliseconds

CHAR .	HORIZONTAL				VERTICAL				DIFFERENT				EQUAL CONT				EQUAL DESC			
LOCAL//	right		left		right		left		right		left		right		left		right		left	
GROUP	C	D	C	D	C	D	C	D	C	D	C	D	C	D	C	D	C	D	C	D
Average	24.20	31.93	20.77	24.16	30.84	34.95	24.24	26.25	36.56	34.96	25.88	27.18	28.79	16.29	23.16	22.07	29.11	27.27	24.14	25.52
Standard de	9.48	18.66	12.46	9.95	15.42	15.97	12.33	10.78	24.19	19.47	13.47	13.97	12.45	16.64	11.03	10.01	21.01	17.65	17.56	14.33
variance	89.95	348.34	155.34	98.98	237.78	255.16	151.92	116.16	585.09	378.94	181.53	195.28	155.10	276.98	121.58	100.30	441.58	311.59	308.30	205.37

Source: Mendes, 2015

Dyslexic and control groups significantly differed in the responses. Dyslexics were always slower than the controls in H, V, D. However there were no significant differences in the continuous identical items (Ic). In the ANOVA statistical analysis the following results were obtained for each variable: Characteristic F (4.4180) = 39.4 p < 0.000001***; Location F (1.4180) = 118 p < 0.000001***; Group F (1.4180) = 0.371 p < 0.542564. The variable characteristic (H, V, D , Ic , Id) was highly significant , and the Ic items presented the shortest fixation latencies , followed by H , Id , V, and D. The latter demanded longer fixation times. For the variable locality, the preference was for the right, in accordance to what has also been found in other studies (Rayner (1998)).

The group variable showed no significant differences, both groups displaying the same pattern of responses in some characteristics. Contrasting the items, the following results are obtained: Characteristics x Locality F (4.4180) = 11.9 p <0.000001***. In this case, the fixation durations were faster to the right (except for Ic in the dyslexic group, that was left); Characteristics X Group F (4.4180) = 19.2 p <0.000001***, in which the control group was always faster in fixation times than the dyslexic group the and Ic item was the most immediate; Location X Group F (1.4180) = 5.47 p <0.019**. This comparison yielded significantly different results, showing that the item which was located on the right was faster and that the control group was faster than the dyslexic, as already observed in several other studies involving response times in dyslexia. When crossing the three variables, the following results were obtained: Characteristics X Location X Group F (4.4180) = 8.24 p <0.000001***, reaffirming that the fastest group was the control which in average fixated items to the right shorter, identifying Ic faster.

Since the fixations to the right are always the most time-consuming as has been observed in other studies (Rayner (1998); Mendes (2008); Barbosa (2012)), it was decided to observe the variables, characteristics and groups, only taking data on the right as relevant. Thus, it is observed that the dyslexic group was slower in items H and V, and, different than one might expect, dyslexics were faster in Ic.

To better define the profile of each group, it is prudent to observe them separately, and thus to understand if there are differences in the treatment of H, V, D and in Ic and Id. The control group will be the first to be observed once it will serve as a baseline, since there is no experiment or testing of this type to be taken as a comparison standard. It was observed that the control group was always faster in stimuli positioned right on the screen, as previously expected. In one arrangement of data in percentage of time the item H was less fixated and the item D was the most fixated. Items V, Ic and Id did not obtain significance in the statistical comparison. Comparing horizontal with vertical factors: ([H] x [V] t (418) = 5.32 p <0.0001 ***). Comparing the distance of the vertices: [Ic] X [Id] t (418) = 0:19 p <0.850), a non significant result.

The dyslexic group was always slower than the control group, except in Ic, which was faster, and in Id that got almost the same control results. The profile of the dyslexic group is significantly different from control, obtaining values that point to the fact that items H, V and D had no differences between them in the scores, being fixated longer than the equal items ([H] X [V] t (418) = 1.78 p <0.076; [H] X [D] t (418) = 1.62 p <0.1049;. [V] X [D] t (418) = 0.01 p <0.9956. Equal items displayed significant differences between each other, Ic is significantly less fixated when compared to Id ([Ic] x [Id] t (418) = 6.56 p <0.0001 ***).

Off-line measures

The fixation durations on words YES and NO were assessed in terms of right and wrong answers. The following table presents the results:

Table 2. Accuracy rates

char .	H				V				D				Ic				Id			
judge .	YES		NO		YES		NO		YES		NO		YES		NO		YES		NO	
group	disl	cont	disl	cont	disl	cont	disl	cont	disl	cont	disl	cont	disl	cont	disl	cont	disl	cont	disl	cont
average	79,81	82,81	47,63	74,32	35,24	26,21	105,33	150,72	21,8	25,72	114,22	145,14	108,97	153,9	20,12	7,7	118,7	147,77	10	8,64
des Standar	58,46	55,93	51,12	72,43	71,53	37,68	62,09	69,93	32,84	44,78	60,54	70,3	57,06	69,27	30,59	11,85	91,34	95,87	24,02	25,4
variance	3417,7	3128,6	2613,36	5246,26	5116,44	1420,1	3854,79	4889,73	1078,63	2005,5	3665,47	4941,99	3255,62	4797,7	935,47	140,35	8342,6	9191	576,75	645,15

Overall there were more right answers than wrong answers, but the dyslexic group made more mistakes than the controls in equal items (Ic e Id). Item H obtained more wrong answers in both groups, but dyslexics got less right items than the controls. The ANOVA results, comparing characteristics (H, V, D, Ic, Id), response accuracy (yes/no) and groups (control and dyslexic) were the following: characteristics F(4,1045)=3,49 p<0,0077***; response accuracy F(1,1045)=31,1 p<0,000001***; group F(1,1045)=117 p<0.000001***. The assessment of interactions between the factors yields the following results: characteristics X accuracy rates (F(4,1045)=561 p<0,000001***); characteristics X accuracy X group F(4,1045)=30,0 p<0,000001***). Other comparisons did not yield significant results: characteristics x group F(4,1045)=0.287 p<0,886; accuracy x group F(1,1045)=0.856).

The control group got accuracy scores equally balanced in D, V, Ic e Id: [V] X [D] t(418)=0,82 p<0,41; [V] X [Ic] t(418)=0,47 p< 0,64; [V] X [Id] t(418)=0,36 p< 0,71; [D] X [Ic] t(418)=1,29 p< 0,19; [D] X [Id] t(418)=0,32 p< 0,74; [Ic] X [Id] t(418)=0.75p< 0.45. The horizontal condition was the lessa accurately answered in comparison with the other conditions ([H] X [V] t(418)=1,.00 p< 0,0001***; [H] X [D] t(418)=10,17 p< 0,0001***; [H] X [Ic] t(418)=11,51 p< 0.0001***; [H] X [Id] t(418)=8,86 p< 0,0001***).

The dyslexic group made significantly more mistakes in condition H in comparison with the other conditions: [H]X [V] t(418)=10,40 p< 0,0001***; [H] X [D] t(418)=12,18 p< 0,0001***; [H] X [Ic] t(418)=11,60 p< 0,0001***; [H]X [Id] t(418)=9,84 p<0,0001***. The other conditions yielded non significant differences: [V]X [D] t(418)=1,49 p<0,13; [V]X [Ic] t(418)=0,63 p<0,53; [V]X [Id] t(418)=1,75 p<0,08; [D]X [Ic] t(418)=0,92 p<0,36; [D]X [Id] t(418)=0,59 p<0,55; [Ic]X [Id]t(418)=1,31 p<0,19.

Discussion

As described above, the region of interest of the analyses is the area of the vertices of the figures. In general, the two groups, control and dyslexic, displayed longer first fixation durations in different figures with relation to equal figures. The cause for this behavior may probably be the fact that subjecs overall would need to inspect different images longer than the equal ones in order to evaluate the existence of similarity or differences between pairs, following the principle of invariance. As reviewed above, this principle governs the neuronal specialization for the recognition of objects and letters, regardless of their spatial position (Tanaka, 2003; Dehaene & Cohen, 2007; Kolinsky & Fernandes, 2014).

Taking into consideration the values for each group, it is clear that the control group was faster when the pictures were different for horizontality. The factor that demanded more cognitive effort than all the other characteristics were the pairs of figures that were different by non-specific characteristics (D), showing that this required more cognitive resources. . This may have happened due to the delay in performing the pairing with figures or similar forms, as already described by other researchers (Biederman, 1987; Dehaene & Cohen, 2007; Kolinsky & Fernandes, 2014). The different figures verticality different figures and the equal figures (continuous or discontinuous) showed no difference in the first fixation durations on the vertex. Exhibiting similar times which were higher than the horizontally different figures, and smaller than the conditions in which the difference was established by other characteristics. It seems then, that this feature is easier to pair in terms of visual invariance. (Biederman,1987; Dehaene & Cohen, 2007; Kolinsky & Fernandes, 2014).

Regarding equal identification, both groups displayed more right answers than wrong answers. More specifically, the control group had more wrong answers in the horizontal different condition, demonstrating that this condition does not seem to be so perceptually sensitive in t

his age group. Notice that this condition was also less fixated by this group. One could speculate that subjects in this age group are not mature enough to perceive right and left symmetry accurately (Cagliari & Cagliari, 1999). Maybe, they fail to draw a parallel between these forms in the horizontal visual plane (Dehaene, 2012; Scliar-Cabral, 2010, 2015).

The dyslexic group has a different behavior when compared to the control group, especially in the perception of the same items. In this respect, the continuity of the stroke appears to be a relevant factor, since fixation times were increased in discontinuous conditions, with enhancement of cognitive demand when traces were discontinuous. Therefore it seems that dyslexics have difficulty recognizing shapes that are equal but do not establish a reference of continuity. It appears that this factor guides the perception of this group, as in the early days of human perception, reflecting the immature perception of brain functioning. Perhaps this is the event of non-neuronal migration in dyslexics. It seems that these individuals would display flaws in the smooth migration of cortical neurons toward the left temporal region, interfering with their connection position between the visual and linguistic areas (Dehaene, 2012). If this is the case, there would be difficulty in matching the images and this would be very relevant if part of the lines is lost, especially those who guide this process, as the vertices (Dehaene & Cohen, 2007; Kolinsky & Fernandes, 2014).

In the different items condition, dyslexics showed no significant difference in processing in comparison with the controls, treating all characteristics within the same latency range. Qualitatively, however, differences can be observed in the pattern of eye fixation between groups. The dyslexic group exhibit evidences of scanning more widely the computer screen, fixating less accurately on the target items than the control group. On the other hand, the control group was faster in identifying the differences in stimuli which were matched by horizontal or vertical features. The vertically different figures were visually inspected in the same average times as the equal figures, no matter whether continuous or discontinuous. The stimuli that demanded more cognitive effort and thus longer latencies were those in the different characteristics groups. The dyslexic group treated the different figures alike, displaying more costly processing for all different figures, regardless of their horizontality or verticality. This group was faster in the perception of the same figures with a continuous path, not being as efficient in figures with a discontinuous stroke. The performance in the off-line measure was similar in both groups, indicating more errors in the horizontal stimuli. The fixation duration time was lower in dyslexics than in the controls.

Conclusions

The eye-tracking experimental study reported here sought to observe the visual behavior of the two groups, control and dyslexic, in the evaluation of pairs of figures and thus verify if there was difference between the groups in the treatment of these figures. Overall, accuracy rates were high in both groups, although the variable group was statistically significant in a between group comparison. It is relevant to point out that dyslexics fixated significantly less than the controls in the demarcated area of the vertices.

The visual behavior of dyslexic proved to be in general less accurate, usually covering the whole screen and not going straight to the target point where stimulus were displayed. Dyslexics showed significantly different behavior than good readers in the perception of equal condition items with continuity of stroke appearing to be directly relevant to the success of dyslexics, since there was increased cognitive demand when the lines were discontinuous. Therefore it seems to be the case that dyslexics have difficulty recognizing discontinuous shapes. It appears that this condition influences the perception of this group, as it used to be the case in the early days of human perception. Dyslexics treated in the same way the different figures, showing no difference in behavior for horizontal, vertical or any other difference. This pattern did not occur in the control group, who showed faster times in the different stimuli by any condition, followed by the vertical condition, taking longer in the horizontal condition. Hence the relevance of promoting the visual processing in reading, not as a central focus, but as necessary in recognizing shapes and letters, especially in dyslexic individuals.

Finally, the results suggest that the continuity of the lines is a relevant factor for the dyslexic group, as in the early days of visual processing, when there was not symmetrization between stimuli. The symmetrization allows the individual to recognize any object, even if rotated on its axis and it has been an evolution guaranteed by neuronal recycling and migration of cells in the composition of synapses for reading in humanity (Dehaene, 2012; 2013; Scliar-Cabral, 2010). Given these results, it is expected that this article can contribute to the advancement of knowledge on dyslexia and reading.

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