Eye movement recordings during reading tasks in children with mixed dyslexia

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Abstract

Introduction and Methodology: *In order to better understand how mixed dyslexia (MD) manifests in the Spanish language, we studied the patterns in eye movements (EM) and errors of omission, inversion, transposition, substitution, addition, semantic change and lexicalization, committed during reading tasks for words, pseudowords and paragraphs, in 30 fourth grade children (15 MD and 15 controls).*

Results and Conclusion: *We found statistically significant differences between cases and controls, where children with MD showed more substitution, omission and repetition errors, together with more fixations and single saccades. These differences result in decreased reading speed and comprehension level of textbooks.*

Keywords: Reading, Learning Disabilities, Dyslexia, Eyes Movements, Children, Neurophysiology, Neuropsychology.

1. Introduction

The eye movement recording technique uses lenses or infrared sensors to detect points to where sight is directed. In the neurosciences, one important application of this technique is the assessment of eye movements (EM) during reading tasks for isolated words, sentences or texts presented word by word (Dell'Osso, & Daroff, 1999; Liversedge, White, Findlay, & Rayner, 2006; Tiaki, Lukasova, & Coutinho de Macedo, 2008).

Such recordings allow the identification of those features in a complex object to which the subject is looking at, paying more attention to and for how long. Furthermore, different variables can be analysed such as the time, duration, type, frequency and length of the EM made (Rayner, 1998).

While reading, words are recognized through EM which allow the subject to identify the stimulus presented. In this recognition process are involved the superior colliculus, located in the midbrain and responsible for the control of ocular motility, and the thalamic nuclei and occipital areas of the cerebral cortex, where discrimination of visual stimuli takes place. Additionally to that control exerted by the midbrain, another process that controls EM takes place in the frontal eye fields (Alcaraz, 2001; Serrano, & Defior, 2004; Vieiro, & Gomez, 2004; Wolf, 2008).

EM made while reading are of two types: fixations and saccades. Fixations, as implied by their name, are ocular activities that target specific areas in the visual field. These stimuli are discriminated in the fovea in relation to both the chromatic and shape traits of the objects; when reading, this process allows the discrimination of grapheme constituents in order to achieve word recognition (Vallés, 2005).

The average duration of a fixation ranges between 200 to 350 msec. This includes a pause between consecutive saccades influenced by the limitations of the neuronal motor response (of about 100-150 msec) (Alcaraz, 2001). Pause duration in fixations depends on the text's characteristics, such as the frequency and length of words as well as the complexity of phrases (Wolf, 2008). In general, 5 to 7 fixations are made in a text line; this number will adjust to the characteristics of the words making up the text. Reading words with 2 or 3 graphemes usually takes only one fixation because the length of these words allows skipping re-focusing them, while words with lengths of 4 to 12 graphemes may require more fixations (Rayner, 1998; Tiaki et al., 2008).

It has been reported that the number of fixations is greater in nouns, adjectives and verbs than in conjunctions, pronouns and prepositions due to the type and length of these grammatical categories. In addition, frequent words are read with a single fixation, its duration being shorter, because the recurrent presentation of words and common phrases allows for a faster identification (Vernon, 1928).

Saccades are characteristic movements of visual exploratory behaviour. There are two types of these movements: single and double saccades. Single saccades allow directing sight from one point to another so that the desired image can be located by the fovea (Czepita, & Lodygowska, 2006). The coverage area of a saccade is of approximately 30° of the visual angle, covering about 8 graphemes. For stimuli exceeding that angle to be captured, a head movement allowing redirecting sight to the part not covered by the saccade is required (Leigh, & Zee, 1991; Vieiro, & Gomez, 2004).

Double saccades are corrective movements occurring because the eye does not always achieve fixation of the exact point required (Alcaraz, 2001). These saccades appear about 10 to 15% of times while reading. It has been proposed that making a greater number of saccades is a result of difficulties in comprehension so that the word has to be read again (Tiaki et al., 2008).

When reading skills are dominated, the length of the single saccades increases while the duration and number of fixations and double saccades decreases. The spatial and temporal dynamics of eye movement coordination during reading has been described, finding that 5% of the double saccades are longer when a word has between 10 and 12 graphemes and 15% are shorter when words contain 2 to 4 graphemes (Heller, & Radach, 1999).

A word is identified by activity of the fovea. The parafoveal vision corresponding to stimuli perceived by the eye periphery provides partial information of the word and serves as an assistant in saccade planning for the next reading point (Vieiro, & Gomez, 2004).

Visual processing through EM together with occipital cortical areas allows to determine the features of graphemes and words, and decide whether to make other saccadic movement or the elements necessary to recall information stored in memory have been already provided for recognition of the word's meaning (Wolf, 2008).

Regarding the reading difficulties observed in children at school age, the Ministry of Public Education (SEP, 2010) reported that, in Mexico, 12.6% of children present reading disorders characteristic of Developmental Dyslexia (DD), which are not associated with lower intelligence or an inadequate teaching-learning process (American Psychiatric Association, 2000; World Health Organization, 2009). Children with DD have intelligence within the normal range, but they make mistakes resulting in slow reading and difficulties in comprehension. It is proposed that DD may result from alterations in nerve structures controlling visual or auditory stimuli.

Adequate auditory discrimination of sounds corresponding to a language allows the conformation of the different phonemic categories. For grapheme-phoneme conversion during the reading process, it is necessary to couple visual discrimination with the corresponding sound. Such process becomes automatic with practice generating orthographic representations, i.e. a mental image of the word is stored in memory so that the words are read in a global manner (Luque, Bordoy, Giménez, Lopez-Zamora, & Rosales, 2011; Pernet, Dufor, & Démonet, 2011).

In the Spanish language, Boder (1970) proposed a classification for DD that is based on reading errors for frequent words describes three types: dyseidetic (DI), dysphonetic (DP) and mixed (MD).

Children with DI read graphemes composing words one by one, which makes their reading slow and analytical. They present omission, transposition and inversion errors. Omissions correspond to deletion of a grapheme or part of a word (e.g. "canero" - "ca*r*nero", "época" - "época*s*"). Transpositions are changes in the order of graphemes or segments within a word or phrase (e.g. "al" - "la", "el" - "le"). Inversions are defined as a difficulty to identify the actual position or real direction of a grapheme (e.g. "b" is confused with "d", "p" with "q", which would lead to reading "*b*escar" instead of "*p*escar" and "*d*icicleta" instead of "*b*icicleta") (Boder, 1970).

DI cases show reading errors related to alterations in the visual system (Boder, 1970). Children with this form of dyslexia do not automatically recognize the words they read, so they extend the usage of attention and memory processes required to identify each grapheme; consequently, these children struggle to identify the meaning and grammatical category of words, thus not achieving a proper understanding of what they read. This type of problems prevents orthographic representations to form, which are important for a comprehensive and efficient reading (Wolf, 2008; Carrillo, Alegría, Miranda, & Sánchez, 2011; Peterson, & Pennington, 2012).

The problems described above in DI have been associated with abnormalities in midbrain regions controlling saccadic EM and thalamic magnocellular cells involved in low-contrast stimuli processing. In addition, such limitations have been linked with disturbances in the primary visual cortex, responsible for capturing the individual features of visual stimuli. It has also been suggested that the occipito-temporal cortex is affected in DI in a region called the visual word form area (VWFA), which is involved in global word recognition (Alcaraz, 2001; Pugh et al., 2001; Pernet et al ., 2011; Peterson, & Pennington, 2012).

Children with DP are unable to perform analysis and synthesis of each grapheme or syllable comprising a word, so they make phonological mistakes called substitutions, which consist of changing a grapheme for another one with a proximate point of articulation (e.g. "car*d*ero" - "car*n*ero", "*e*stucia" - "*a*stucia"). They also add up a grapheme, a syllable or a word to their reading, an error called addition (e.g. read "tontolobo*bo*" instead of "tontolobo", "per*o*siguió" instead of "persiguió"). Other errors in which DP children incur are: semantic changes and lexicalizations. A semantic change is when one word with a certain meaning is replaced with a different word of a similar meaning (e.g. "quería" instead of "quieres", "llamó" instead of "llamaban"). A lexicalization is when a word with particular meaning and visual configuration is replaced with a word of similar visual configuration (i.e. respecting the beginning or end of the word and its length) but different meaning (e.g. "planta" - "alta", "pequeña" - "peña") (Boder, 1970). DP reading is global and repetitive (Boder, 1970).
Reading errors in DP children suggest auditory alterations linked with processes of acquisition of phonological awareness (Boder, 1970; Sprenger-Charolles, 2011). Phonological awareness is the ability to identify and consciously manipulate phonemes corresponding to a language (Luque et al., 2011). Abnormalities in the processes described above result in an inadequate and deficient identification of frequent words and pseudowords, with consequent low fluency and comprehension level; it has been proposed that these may be associated with abnormalities in cortical regions involved in language reception and production, such as the left posterior temporal cortex, supramarginal gyrus of the parietal cortex and inferior frontal cortex (Pugh et al., 2001; Pernet et al., 2011; Peterson, & Pennington, 2012).
In MD, both dyseidetic and dysphonetic difficulties are observed, where there may be dominance of one type over the other (Boder, 1970).
In the English language, several studies have suggested that dyslexic children usually make mistakes while reading words such as: omissions ("approch" instead of "appro*a*ch"), inversion of graphemes "b", "d" and "p" ("d*ǽ*d" or "p*ǽ*d" instead of "bad") and transpositions ("was" instead of "saw" or "god" instead of "dog"). Nevertheless, other errors have also been described, such as additions (e.g. in the word "situation" they read "situa*r*tion"), substitutions (e.g. in those who say "kle*n*e" instead of "cle*a*n", "re*e*lly" instead of "re*a*lly"), lexicalizations (e.g. reading "witch" instead of "which") and errors related to the separation of letters in a word (e.g. reading "alot" instead of "a lot", "sub marine" instead of "submarine") (Fischer, Liberman, & Shankweiler, 1978; Heinz, & Heinz, 2000; Bourassa, & Treiman, 2003; Rello, Baeza-Yates, Saggion, & Pedler, 2012).
Regarding EM, in general, it has been observed that dyslexic children make a greater number of fixations and saccades than other children. While dyslexic children make 7 to 10 fixations to read a word of 10 or 12 graphemes, non-dyslexics adjust the length of the saccadic movements to span more words regardless of their length, thus making 5 to 7 fixations in a text line consisting of 4 words. This has led researchers to suggest children with dyslexia have difficulties in the recognition and integration of visual stimuli, resulting in an increase in the time required to process visual information or to plan and execute the next saccadic movement (Abdeldayem, & Selim, 2005; Ram-Tsur, Faust, Caspi, Gordon, & Zivotofsky, 2006; Martelli, Di Filippo, Spinelli, & Zoccolotti, 2009).
Investigations on binocular coordination of saccades in dyslexic and control children, the first one have shown alterations in this process, so that it has been proposed an immaturity of oculomotor control regulated by the magnocellular system and cerebellum as the cause of such abnormalities (Pia Bucci, Brémond-Gignac, & Kapoula, 2008; Fischer, & Hartnegg, 2008). Additionally, difficulties in convergent and divergent movements necessary for proper targeting of near and far objects should also be attributed to this immaturity (Kapoula et al., 2007; Preilowski, & Matute, 2011).

There are no reports in the literature of comparative analyses between the types of errors and the characteristics of eye movements in MD during reading tasks for words or pseudowords, nor are there reports for sentences and paragraphs. These studies would provide more information regarding the neuropsychological and neurophysiological alterations in MD (Moll, Hutzler, & Wimmer, 2005; De Luca et al., 1999; Sparrow, & Miellet, 2002).

A broader knowledge of MD reading characteristics in a transparent language such as Spanish, as opposed to most studies which are carried out in the opaque English language, together with eye movement recordings proposed as a complementary neurophysiological tool for the diagnosis (Carrillo et al., 2011; Richlan, 2012), will allow teachers and therapists to implement intervention strategies directed to specific difficulties, facilitating a reduction of the observed problems and their severity. The objective of this study was to describe dyslexia characteristics in the Spanish language, considering the number and type of eye movement patterns and errors made during reading tasks for words, pseudowords and paragraphs in fourth grade children with mixed developmental dyslexia.

2. Subjects and methods

We performed an observational, descriptive and transversal study of 30 right-handed fourth grade male children: 15 showing correct reading and comprehension levels and 15 with MD, ages ranging from 8 years and 10 months to 10 years and 6 months, and Intelligence Quotient (IQ) $\geq$ 80. Mean age was 9 years and 5 months (SD $\pm$ 4.5 months).

Children comprising our sample were invited, with parental consent, to participate in a neuropsychological study, with a 30 minutes session, to be conducted in the Laboratory of Psychobiology at the Faculty of Psychology, University of Veracruz, Campus Xalapa. All children attended public schools from the city centre's surrounding area of Xalapa, Veracruz, México, and had a medium-low socioeconomic status.

Study participants were selected after applying neuropsychological tests to children picked randomly from a list, facilitated by their teachers, containing the names of children considered "normal" and those in whom learning difficulties had been identified. Inclusion criteria for controls considered average or above average scoring in the Lectura en Voz Alta (Aloud Reading) and Precisión en la Recuperación Escrita (Accuracy in Written Recall) tests from the Evaluación Neuropsicológica Infantil (Neuropsychological Assessment of Children, ENI) (Matute et al., 2007) battery. For dyslexic children, inclusion required meeting literacy problems described for Developmental Dyslexia (DD), presenting 5 or more errors in the mentioned tests and low comprehension level. The number of errors corresponding to each age group was determined by the "low" and "extremely low" percentile ranks assigned relative to the total number of errors for each literacy test of ENI applied. When analysing the type and frequency of reading errors in DD children, we identified both visual and auditory difficulties, for which they were subsequently classified as MD children.

To study fixations and single and double saccades, we recorded EM during the Reading Aloud task using a X120 Eye Tracker TOBII equipment coupled with Attention Tools v.4.3 software. This method uses infrared sensors to record pupil movements and determine the exact location of the child's eyes, projects the visual stimuli and saves the recording.

To start the recordings, each child was asked not to move and to see each of the nine calibration red circles on a 17" flat screen with 1280 x 1024 pixels resolution, placed at a distance of 60 cm from both the child's eyes and the equipment's sensor. Further calibration required the child to look at the centre of an image with black spots. We started testing by asking the child to read aloud stimuli presented on different screens: 10 words and 10 pseudowords from the Evaluación de la Conciencia Fonológica (Assessment of Phonological Awareness, Ecofon) (Matute, Montiel, Hernández, & Bugarin, 2006), and a 40-word paragraph from ENI (Matute, Rosselli, Ardila, & Ostrosky-Solís, 2007). Reading time for each screen was fixed at 30 sec.

We performed qualitative and quantitative analyses for EM while reading, as well as for visual (omissions, transpositions and inversions) and auditory (substitutions, additions, semantic changes, lexicalizations and repetition) reading errors made during the tasks.
For quantitative analysis, we obtained for MD and controls: the average and frequency of visual and auditory errors, the number of fixations and single and double saccades, and the reading times.
For the statistical analysis, we performed one-way analysis of variance (ANOVA) using the statistical software JMP Version 8 and graphed results using GraphPad Prism 5.

3. Results

3.1 Reading isolated words

For the reading task of isolated words, MD children made more substitutions and inversions (four errors in both cases). For example, in substitutions they read: "gavil*o*nes" instead of "gavil*a*nes", where they changed "a" for "o"; "enferm*e*ba" instead of "enferm*a*ba", changing "a" for "e"; "g*ui*vilanes" instead of "g*a*vilanes", changing "a" for "i". Inversions included reading "enferma*d*a" instead of "enferma*b*a", where they changed the spatial arrangement of the grapheme "d" for "b". These children also made repetitions of syllables such as "ga-gavilanes" and "sol-solitario", of segments of a word as in "leva-levantarse" and "enferma-enfermaba", as well as progressive word constructions like "enfer-enfer-enfermaba" and "ga-gavila-gavilanes". There were only two types of errors in controls: substitutions and lexicalizations (same amount of both). No statistically significant differences were found between MD and control for this task.
Regarding EM for this task, MD children made 40 fixations, 32 single saccades, 7 double saccades and had a reading time of 14 sec, while controls made 30 fixations, 22 single saccades, 6 double saccades and had a reading time of 11 sec (Figure 1).
We found significant differences between MD and controls for fixations ($F_{(1, 28)} = 8.5169$, $p < 0.007$) and single saccades ($F_{(1, 28)} = 15.0123$, $p < 0.0006$). For MD, the number of fixations when making substitutions ($F_{(1, 28)} = 4.2281$, $p < 0.0006$) and repetitions ($F_{(1, 28)} = 6.1489$, $p < 0.01$), the number of single saccades when making inversions ($F_{(1, 28)} = 5.3007$, $p < 0.02$), the number of double saccades when making lexicalizations ($F_{(1, 28)} = 6.7024$, $p < 0.01$), and found increased reading time when making substitutions ($F_{(1, 28)} = 4.5009$, $p < 0.04$), lexicalizations ($F_{(1, 28)} = 9.5802$, $p < 0.004$) and repetitions ($F_{(1, 28)} = 5.8255$, $p < 0.02$).

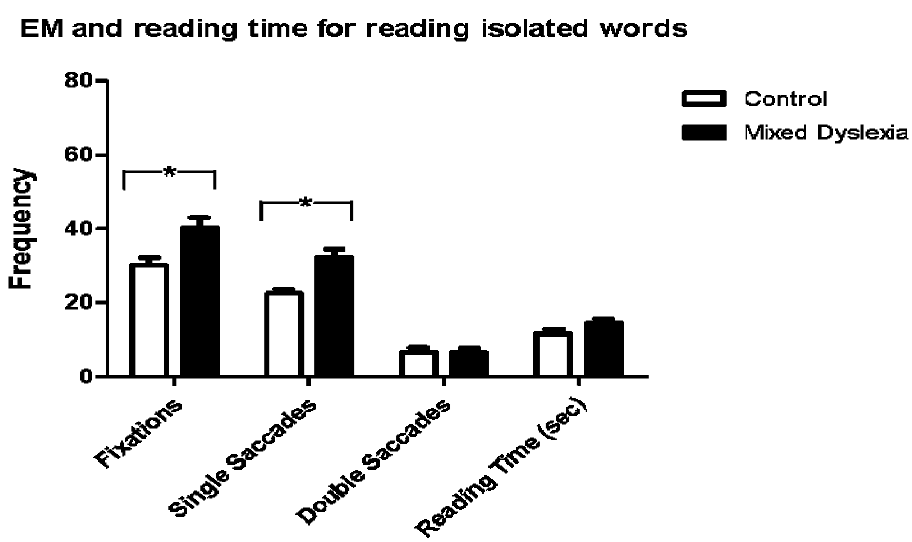

Figure 1. Frequencies for EM and reading time while reading isolated words in children with MD and controls. Results are expressed as the mean ± SEM. Differences were considered significant at $p \leq 0.05$.

3.2 Reading pseudowords

For pseudowords, MD children made 24 substitution errors. Some examples are: "tr*a*busendo" instead of "tr*e*busendo", changing "e" for "a"; "*i*mpisendi" instead of "*u*mpisendi", where they read "u" for "i"; "t*e*rceapuli" instead of "torceapuli", where they read "o" for "e"; and "*s*esafuli" instead of "*n*esafuli", reading "n" for "s". Repetitions of letters such as "a-aspuriense", non-word segments like "aspu-aspuriense", "nesa-nesafuli" and "umpi-umpisendi", and whole pseudowords were also observed in MD. Control children made 6 substitutions and 5 additions. Significant differences were found in the number of substitution errors for this task ($F_{(1, 28)} = 7.2551$, $p<0.01$).

For EM, MD children made 54 fixations, 44 single saccades and 8 double saccades in 21 sec, while control children made 42 fixations, 33 single saccades and 8 double saccades in 17 sec (Figure 2). Significant differences were found between MD and controls for auditory errors ($F_{(1, 28)} = 4.3822$, $p <0.005$), fixations ($F_{(1, 28)} = 7.6165$, $p <0.01$), single saccades ($F_{(1, 28)} = 11.1652$, $p <0.002$) and reading time ($F_{(1, 28)} = 5.6383$, $p <0.02$). For MD, differences were found in the number of fixations when making substitutions ($F_{(1, 28)} = 14.3589$, $p <0.0007$) and repetitions ($F_{(1, 28)} = 12.0931$, $p <0.001$)), and the number of single saccades when making substitutions (F (1, 28) = 14.7986, $p <0.0006$) and repetitions ($F_{(1, 28)} = 14.1509$, $p <0.0008$). Also, reading time increased when making repetitions ($F_{(1, 28)} = 39.0937$, $p <0.0001$).

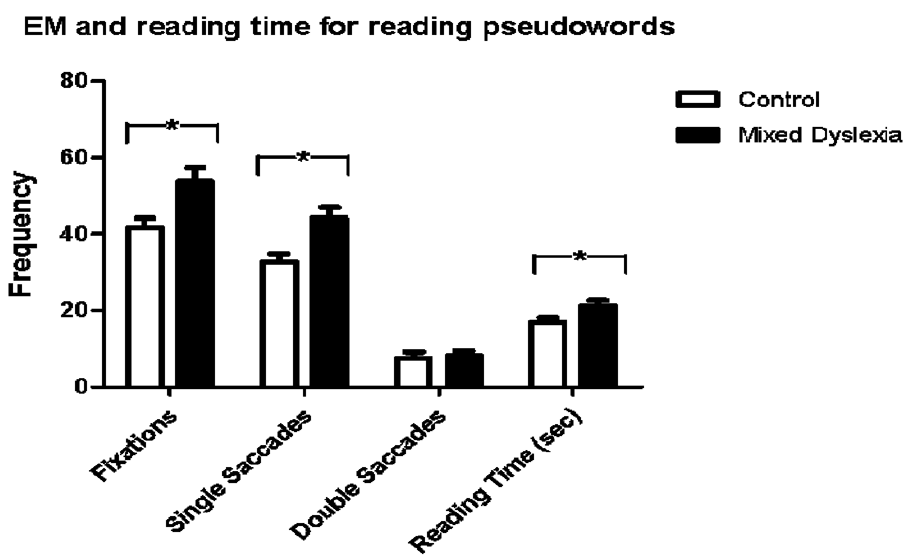

Figure 2. Frequencies for EM and reading time while reading pseudowords in children with MD and controls. Results are expressed as the mean ± SEM. Differences were considered significant at $p \leq 0.05$.

3.3 Reading a paragraph

While reading the paragraph, MD children made 11 omissions and 7 lexicalizations. As examples, for omissions was read "otra" instead of "otra*s*", eliminating the grapheme "s" at the end of the word, "asucia" was read instead of "as*t*ucia", where the grapheme "t" was omitted; for lexicalizations was read "carnicero" instead of "carnero". We also found repetitions of letters such as "é-épocas" and "o-otras", word segments as in "épo-épocas", and whole words like "tontolobo-tontolobo", successions of words such as in "y al que-y al que" and "de otras-de otras", and some progressive word constructions as in "to-ton-tontolobo". Control children made 6 omissions and 5 additions. Significant differences were found for substitutions ($F_{(1, 28)} = 7.2551$, $p <0.01$) and repetitions ($F_{(1, 28)} = 10.7561$, $p <0.002$).

For EM, MD children made 62 fixations, 61 single saccades and 13 double saccades in 19 sec while controls made 42 fixations, 31 single saccades and 11 doubles saccades in 14 sec (Figure 3). Significant differences were found between MD and controls for auditory errors ($F_{(1, 28)}$ = 9.9833, p <0.003), fixations ($F_{(1, 28)}$ = 18.5385, p <0.0002), single saccades ($F_{(1, 28)}$ = 6.9755, p <0.01) and reading time ($F_{(1, 28)}$ = 12.4472, p <0.001). In MD, we found differences in the number of fixations when making transpositions ($F_{(1, 28)}$ = 4.3659, p <0.04), substitutions ($F_{(1, 28)}$ = 12.6481, p <0.001), semantic changes ($F_{(1, 28)}$ = 4.9826, p <0.03), lexicalizations ($F_{(1, 28)}$ = 6.8253, p <0.01) and repetitions ($F_{(1, 28)}$ = 19.0472, p <0.0002), as well as in the number of double saccades which associated with repetitions ($F_{(1, 28)}$ = 6.0156, p <0.02). Substitutions also increased reading time in MD ($F_{(1, 28)}$ = 14.7281, p <0.0006), as did lexicalizations ($F_{(1, 28)}$ = 10.9249, p <0.002) and repetitions ($F_{(1, 28)}$ = 29.1991, p <0.0001).

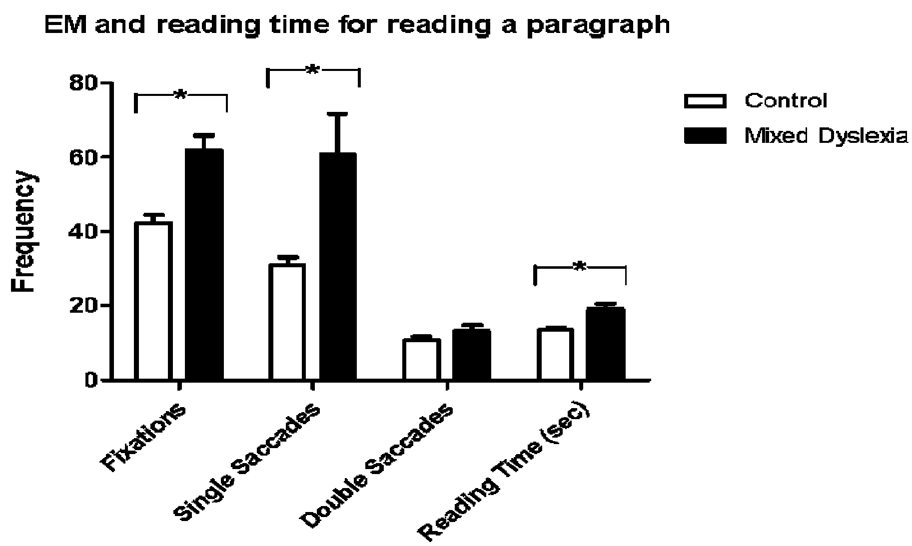

Figure 3. Frequencies for EM and reading time while reading a paragraph in children with MD and controls. Results are expressed as the mean ± SEM. Differences were considered significant at p ≤ 0.05.

4. Discussion

Auditory errors dominated in MD, with an increased number of substitutions, semantic changes and lexicalizations compared to controls. Boder (1970) mentions that there may be dominance of either auditory or visual errors in children with MD. In our study, we found auditory to dominate over visual errors.

Auditory errors reflected difficulties in phonological decoding, an important process in reading, resulting in a slow repetitive reading. This suggests MD children have difficulties identifying the phoneme corresponding to each particular grapheme constituting a word, which has been reported by other authors as well (Luque et al., 2011).

The highest number of auditory errors occurred when reading pseudowords, which reflects difficulties in the grapheme-phoneme conversion process, as stated by other authors (Duranovic, Huseinbasic, & Tinjak, 2012). Such difficulties may be associated with abnormalities in temporo-parietal brain regions, where it is widely known that phonological processing and grapheme-phoneme conversion take place (Pernet et al., 2011, Peterson, & Pennington, 2012).

MD children also had omission errors when reading a paragraph. This type of errors reflects difficulties for an adequate integration of the visual features of graphemes constituting a word (Carrillo et al., 2011), which may be associated with abnormalities in temporo-occipital brain regions involved in global word recognition. All of this allows us to assume that, as previously proposed, the dorsal and ventral pathways of the visual system, involved in the identification of the spatial location and features corresponding to graphemes, are altered in MD (Pernet et al., 2011; Peterson, & Pennington, 2012).

It is of importance to note that reading errors found in MD cases in the opaque English language have been limited to grapheme omissions, substitutions, additions and inversions. However, in the semitransparent Spanish language, we found herein these errors occurred in syllables, words and sentences as well, in accordance to what others have reported (Rello et al., 2012). Furthermore, only vowel substitutions have been reported for the English language (Fischer et al., 1978), such as “a” for “o”, “i” for “u”, “e” for “a”, “a” for “u”, while we also observed substitutions of consonants in Spanish, like “r” for “n”, “m” for “n”, “s” for “n”, “f” for “s” or “ll” for “l”.

Additionally, we observed repetitions of parts of whole words and pseudowords, and even word constructions. Some repetitions in our MD children appeared as progressive word constructions, a strategy these children use to solve their reading difficulties that deserves further investigation.

From all the above, we can conclude there are differences in the type of reading errors made by MD children between the Spanish and English languages, particularly in the case of substitutions. Vowel substitutions in English have a phonological character, while consonant substitutions in Spanish seem to have more of a visual nature. This highlights the need for studying MD difficulties in semitransparent languages.

Finally, eye movement recordings reported an increased number of fixations and saccades associated with substitution, transposition, inversion and lexicalization errors in MD with respect to controls. We believe our results suggest the eye movement recording technique as a suitable neurophysiologic tool to complement the neuropsychological diagnosis of developmental dyslexia and aid with the selection of adequate therapeutic interventions to help these children overcome their difficulties.

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6. References

Abdeldayem, H., & Selim, O. (2005). Neuropsychological Assessment and EEG Evaluation of Dyslexic Children. The Internacional Journal of Child Neuropsychiatry, 2(2), 155-162.

American Psychiatric Association. (2000). Diagnostic and Statistical Manual of Mental Disorders (4a ed., text rev.). Washington, DC: Autor.

Alcaraz, V. M. (2001). Visión. En Alcaraz, V. M. (Ed.), Estructura y función del sistema nervioso: Recepción sensorial y estados del organismo (pp. 123-148). México: Manual moderno, Universidad de Guadalajara y Facultad de Psicología UNAM.

Boder, E. (1970). Developmental dyslexia: A new diagnostic approach based on the identification of three subtypes. Journal of School Health, 40(6), 289-90.

Bourassa, D., & Treiman, R. (2003). Spelling in Children with Dislexia: Analyses from the Treiman-Bourassa early spelling test. Scientific studies of reading, 7(4), 309-333.

Carrillo, M. S., Alegría, J., Miranda, P., & Sánchez, N. (2011). Evaluación de la dislexia en la escuela primaria. Prevalencia en español. Escritos de Psicología, 4(2), 35-44. doi: 10.5231/psy.writ.2011.1407.

Czepita, D., & Lodygowska, E. (2006). Role of the organ of vision in the course of developmental dyslexia. Klínica Oczna, 108(8), 110-3.

De Luca, M., Di Pace, E., Judica, A., Spinelli, D., & Zoccolotti, P. (1999). Eye movement patterns in linguistic and non-linguistic tasks in developmental surface dyslexia. Neuropsychologia, 37, 1407-1420.

Dell´Osso, L. F., & Daroff, R. B. (1999). Eye movement characteristics and recording techniques. En Glaser, J. S. (Ed.), Neuro-ophthalmology (pp. 327-343). Estados Unidos: Lippincott Williams & Wilkins.

Duranovic, M., Huseinbasic, M., & Tinjak, S. (2012). Development of phonological awareness and letter knowledge in Bosnian preschool children. International Journal of Linguistics, 4(2), 18-34.

Fischer, B., & Hartnegg, K. (2008). Saccade control in dyslexia: Development, deficits, training and transfer to reading. Optometry & Vision Development, 39(4), 181-190.

Fischer, F. W., Liberman, I. Y., & Shankweiler, D. (1978). Reading reversals and developmental dyslexia: a further study. Cortex, 14, 496-510.

Heinz, M., & Heinz, W. (2000). Pseudoname learning by German-speaking children with dyslexia: Evidence for a phonological learning deficit. Journal of Experimental Child Psychology, 75, 116-133.

Heller, D., & Radach, R. (1999). Eye movements in Reading. Are two eyes better than one?. En Becker, W., Deubel, H. & Mergner, T. (Eds.). Current Oculomotor Research. Physiological and Psychological Aspects (pp. 341-348). New York: Kluwer Academic y Plenum Publishers.

Jiménez, J. E., & Ramírez, G. (2002). Identifying subtypes of reading disability in the Spanish language. The Spanish Journal of Psychology, 5(1), 3-19.

Kapoula, Z., Pia Bucci, M., Jurion, F., Ayoun, J., Afkhami, F., & Brémond-Gignac, D. (2007). Evidence for frequent divergence impairment in French dyslexic children: deficit of convergence relaxation or of divergence per se?. Graefe´s Archive for Clinical and Experimental Opthalmology, 245, 931-936. doi: 10.1007/s00417-006-0490-4.

Leigh, R. J., & Zee, D. S. (1991). The neurology of the eye movement. Philadelphia: Davis.

Liversedge, S. P., White, S. J., Findlay, J. M., & Rayner, K. (2006). Binocular coordination of eye movements during reading. Vision Research, 46(15), 2363-2374. doi:10.1016/j.visres.2006.01.013.

Luque, J. L., Bordoy, S., Giménez, A., López-Zamora, M., & Rosales, V. (2011). Severidad en las dificultades de aprendizaje de la lectura: diferencias en la percepción del habla y la conciencia fonológica. Escritos de Psicología, 4(2), 45-55. doi:10.5231/psy.writ.2011.2807.

Martelli, M. L., Di Filippo, G., Spinelli, D., & Zoccolotti, P. (2009). Crowding, reading and developmental dyslexia. Journal of vision, 9(4):14, 1-8. doi:10.1167/9.4.14.

Matute, E., Montiel, T., Hernández, C., & Bugarin, J. M. (2006). Evaluación de la Conciencia Fonológica-ECOFON. México: Universidad de Guadalajara.

Matute, E., Rosselli, M., Ardila, A., & Ostrosky-Solís, F. (2007). Evaluación Neuropsicológica Infantil (ENI). México: Manual Moderno.

Moll, K., Hutzler, F., & Wimmer, H. (2005). Developmental dyslexia in a regular orthography: A single case study. Neurocase, 11, 433-440. doi: 10.1080/13554790500263537.

Pernet, C. R., Dufor, O., & Démonet, J. F. (2011). Redefiniendo la dislexia: explicando la variabilidad. Escritos de Psicología, 4(2), 17-24. doi: 10.5231/psy.writ.2011.24072.

Peterson, R. L., & Pennington, B. F. (2012). Developmental dyslexia. Lancet, 379, 1997- 2007. doi:10.1016/S0140-6736(12)60198-6.

Pia Bucci, H., Brémond-Gignac, D., & Kapoula, Z. (2008). Poor binocular coordination of saccades in dyslexic children. Graefe´s Archive for Clinical and Experimental Ophtalmology, 246(3), 417-428. doi: 10.1007/s00417-007-0723-1.

Preilowski, B. & Matute E. (2011). Diagnóstico Neuropsicológico y terapia de los trastornos de lectura-escritura (Dislexia del Desarrollo). Revista Neuropsicológica, Neuropsiquiatría y Neurociencias, 11, 1, 95-122.

Pugh, K. R., Mencl, W. E., Jenner, A. R., Katz, L., Frost, S. J., Lee, J. R., Shaywitz, S. E., & Shaywitz, B. A. (2001). Neurobiological studies of reading and reading disability. Journal of Communication Disorders, 34, 479-492.

Ram-Tsur, R., Faust, M., Caspi, A., Gordon, C. R., & Zivotofsky, A. Z. (2006). Evidence for ocular motor deficits in developmental dyslexia: Application of the double-step paradigm. Investigative Ophthalmology & Visual Science, 47, 4401-4409. doi: 10.1167/iovs.05-1657.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. Psychological Bulletin, 124(3), 372-422.

Rello, L., Baeza-Yates, R., Saggion, H., & Pedler, J. (2012). A first approach to the creation of a spanish corpus of dyslexic texts. En LREC Workshop Natural Language Processing for Improving Textual Accessibility (NLP4ITA), Istanbul: Turkey.

Richlan, F. (2012). Developmental dyslexia: Dysfunction of a left hemisphere reading network. Frontiers in Human Neuroscience*,* 6(120), 1-5. doi:10.3389/fnhum.2012.00120.

Serrano, F., & Defior, S. (2004). Dislexia en Español: estado de la cuestión. Revista Electrónica de Investigación Psicoeducativa y Psicopedagógica, 2(2), 13-34.

Sistema Educativo Público de los Estados Unidos Mexicanos (SEP): principales cifras ciclo escolar 2010-2011. México: Autor.

Sparrow, L., & Miellet, S. (2002). Activation of phonological codes during reading: Evidence from eye movements. Brain and Language, 81, 509-516.

Sprenger-Charolles, L. (2011). Subtipos de dislexia en lenguas que difieren en la transparencia ortográfica: inglés, francés y español. Escritos de Psicología, 4(2), 5-16. doi: 10.5231/psy.writ.2011.1707.

Tiaki, M., Lukasova, K., & Coutinho de Macedo, E. (2008). Movimentos oculares na leitura de palavras isoladas por jovens e adultos em alfabetização. Psicología: Teoría e Prática, 10(1), 113-124.

Vallés, A. (2005). Comprensión lectora y procesos psicológicos. Liberabit. Revista de Psicología, 11, 49-61.

Vernon, M. D. (1928). The movements of the eyes in reading. The British Journal of Ophthalmology, 12, 130-139.

Vieiro, P., & Gómez, I. (2004). Psicología de la lectura. Procesos, teorías y aplicaciones instruccionales. Madrid: Pearson Educación.

Wolf, M. (2008). Como aprendemos a leer. Historia y ciencia del cerebro y la lectura. Barcelona: Ediciones B.

World Health Organization. (2009). The International Classification of Diseases, vol 10: Classification of Mental and Behavioral Disorders. Geneva: Autor.