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Text complexity and eye movements measures in adults readers*

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Abstract: This study aimed to investigate eye movement patterns of adults normal readers, while reading texts with two different degrees of difficulty, and with three distinct texts: everyday situations, textbooks and newspapers. Twenty-four participants read texts aloud while monocular eye movements were recorded and answered questions related to text comprehension. Results indicated that the average reading time by word, number of ocular fixations and number of regressive saccades, varied according to complexity and theme of texts. Data were discussed considering the increase in cognitive demand required for reading comprehension, such as semantic integration skills, working memory and the occurrence of inferences. This data can help in the construction of assessment tools for subjects with developmental dyslexia.

Keywords: ocular fixation; reading; evaluation; word processing; adult.

COMPLEXIDADE DO TEXTO E MEDIDAS DE MOVIMENTOS OCULARES EM ADULTOS LEITORES

Resumo: O objetivo deste trabalho foi investigar padrões de movimentos oculares de adultos bons leitores durante a leitura de textos com dois níveis de dificuldades e com três tipos de conteúdo: situações cotidianas, textos didáticos e jornalísticos. Vinte e quatro participantes leram os textos em voz alta enquanto o movimento monocular foi gravado e responderam a questões relacionadas à compreensão dos textos. Resultados indicam aumento da média de tempo de leitura por palavra, do número de fixações e de sacadas regressivas de acordo com a complexidade e o assunto do texto. Os dados foram discutidos em função do aumento de demanda cognitiva e utilizados para a compreensão do texto, como habilidades de integração semântica, memória de trabalho e inferências. Esses dados auxiliam na construção de instrumentos de avaliação para indivíduos disléxicos.

Palavras-chave: fixação ocular; leitura; avaliação; processamento de textos; adulto.

LA COMPLEJIDAD DEL TEXTO Y LAS MEDIDAS DE LOS MOVIMIENTOS OCULARES EN LECTORES ADULTOS

Resumen: Este trabajo tuvo como objetivo investigar los patrones de movimiento oculares de adultos buenos lectores en textos con dos niveles de dificultad y tres tipos

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de contenido: situaciones cotidianas, libros de texto y textos periodísticos. Veinticuatro participantes leyeron los textos en voz alta com grabacion de movimiento monocular en cuanto respondían a preguntas de comprensión. Resultados indican aumento del tiempo promedio de lectura por cada palabra, número de fijaciones y sacadas regresivas oscilaron según la complejidad y el contenido del texto. Los datos fueron discutidos de acuerdo com el aumento de la demanda cognitiva necesaria para la comprensión del texto como las habilidades de integración semántica, memoria de trabajo y deducciones. Estos datos ayudan en la construcción de instrumentos de evaluación para sujetos disléxicos.

Palabras clave: fijación ocular; lectura; evaluación; procesamiento de texto; adulto.

Understanding cognitive and behavioral processes during reading is fundamental to verify how underlying skills are typically developed as well as being able to identify deficits observed in individuals with learning disorders. Reading and writing have a key role in the development and propagation of knowledge today. In this sense, individuals who don't achieve a certain level of domain in these processes, in general, are marginalized in the educational system and the job market. Therefore, it's necessary to expand the knowledge of reading processing that provide the bases for creation of effective assessment and intervention tools.

Word recognition can be understood by using the dual-route model of reading, which explains transforming print to sound through the phonological route or the lexical route (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). In the phonological route, word recognition occurs by the decoding and converting of graphemes to phonemes. The phonological processes begin with the conversion of parts of segments, word spelling into sounds and phonological segments until the pronunciation of the word is reached. Furthermore, the use of phonological routes enable reading of new or pseudo words. Moreover, in lexical route, the pronunciation occurs by the recognition of the word as a whole. This process begins with the recognition of pre-stored orthographic word representation in mental spelling lexicon, which in turn activates the semantic lexicon.

In turn, cognitive models have been constructed to explain the reading process and comprehension of sentences and texts. According to Gough and Tunmer (1986), reading comprehension results from the interaction between components of the overall decoding and linguistic comprehension. Subsequent studies have consistently supported the model of these authors, despite suggesting replacing the word decodification with the expression word recognition. Other skills also integrate the model of reading competence, such as processing speed or reading fluency (Tilstra, McMaster, Broek, Kendeou, & Rapp, 2009). In addition, Oakhill, Cain and Bryant (2003) found that the ability for textual integration, knowledge of story structure, metacognitive monitoring skills and working memory contribute significantly to reading comprehension performance. Evidence also suggests that although both word recognition and linguistic comprehension are fundamental and necessary for reading comprehension, the relative importance of each of them seems to change with educational advancement. The role of word recognition skills, for example, tends to decrease as children

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advance in school from elementary school to high school, while understanding the importance of language tends to increase (Oakhill *et al*., 2003; Tilstra *et al*., 2009).

The study of the pattern of eye movements in reading tasks began in the XVII century through observations of Louis Émile Javal, a French ophthalmologist (Henderson, 2006). Since then, with the development and improvement of technology, researches on eye movements have measured more specific and accurate characteristics using different eye tracking systems. Amongst the properties of eye movements, there are some general measures, such as number and duration of fixations, progressive saccades, regressive saccades and re-fixations. During the reading process, the eye pattern differs in comparison to that which was observed in other tasks. Typically, the distance between one fixation and another is around 7-9 letters (Rayner, 1998; Joseph, Liversedge, Blythe, White, & Rayner, 2009). It is considered that the function of the saccades are to find words that will be decoded by the fixations as well as during the fixations where the symbols are processed in the fovea.

Studies have also shown that duration of eye fixations in reading varies between 225-275 milliseconds and are more frequently observed in words with three or more letters. They often occur in the middle or at the beginning of the word and may occur again depending on the word length. When fixations occur in the first half of the word, they enable both foveal and parafoveal processing. In normal readers, the distance between the fixations is usually higher than in poor readers, which makes their reading faster. About 30% of words are not fixated and this phenomenon is named word skipping. Usually words of high frequency in language or of high incidence in the text are skipped and it doesn't affect the reading comprehension. In successful reading, progressive saccades are predominantly observed (Rayner, 1998). However, between 10 and 15% of the reading saccades occur in the opposite direction, being the regressive saccades. These saccades indicate the need of further inspection of words which are unread or not understood (Starr & Rayner, 2001). According to Murray and Kennedy (1998), normal readers have fewer regressive saccades, compared those of poor readers.

Visual tasks that require detailed information acquisition from different areas, as reading sentences and texts, involve execution of sequences of saccades (Inhoff, Solomon, Seymour, & Radach, 2008). Furthermore, changes in fixation localization between eyes tend to be related to stimulus orientation, letter size and word length. Since during reading stimuli are left-right oriented and readers must to execute a sequenced saccades pattern, Inhoff *et al*. (2008) haven't found significant differences between left and right eye movement pattern during word reading.

Joseph *et al*. (2009) conducted an experiment with children and adults with normal reading abilities. During the tasks, normal sentences were presented and half of them contained a word length manipulation; such that the critical word was either four or eight letters long. Results showed no differences between reading time, number and duration of ocular fixations in both presentation conditions in adults. However,

children presented longer durations of fixations and of reading time in sentences as well as higher numbers of fixations and regressive saccades than in adults.

In order to verify if reading comprehension of sentences change according to stereoscopic manipulations, Schotter *et al*. (2012) evaluated normal adult readers in four types of sentences: with no depth cues, with a monocular depth cue that implied the sentences loomed out of the screen, with a congruent monocular and binocular depth cues and with an incongruent monocular and binocular depth cue. Results indicated no differences in comprehension related to the type of manipulation. In this sense, changes in depth does not make it difficult for the cognitive processing of reading, even in the incongruent condition the fixation time is more than other conditions.

Macedo, Yokomizo, Ariente, Koakuto and Schwartzman (2007) verified the eye movement pattern during the reading of words and pseudo-words in typical native Brazilian, Portuguese speaking college students. Results showed a relationship between eye movement measures and psycholinguistic characteristics of words. The number of fixations, first fixations of time and total time of fixations, varied according to the length and frequency of words. Furthermore, the same measures were lower for the short length words compared to the medium and long length words. In the same period, Yokomizo, Lukasova, Fonteles and Macedo (2008) evaluated the ocular pattern during reading of children's fables with children and normal college readers. Children presented higher numbers of regressive saccades than college readers, but the pattern of regressive saccades and type of words that suffered regression was similar in both groups. Both groups have made more inter-word regressions in nouns, adjectives and verbs. Also, a higher number of regressive saccades were observed in the beginning of each line of the text, which can be explained by paraphoveal processing in reading.

Miyata, Minagawa-Kawai, Watanabe, Sasaki and Ueda (2012) found correlations between reading speed, accuracy and measures of eye movements, being that fast readers showed lower fixations and larger saccades than average and slow readers. Other experiment showed that adults with higher levels of qualifications in an area of knowledge had the lowest rates of regressive saccades in unknown and common words as well as less time spent rereading information (Jian & Ko, 2012). Thus, the present study aimed to investigate the pattern of eye movements with monocular measures of normal college readers during reading of texts with two degrees of complexity (simple and complex) and different themes (i.e., everyday situations, texts from textbooks and journalistic texts).

Method

Participants

Twenty-four adults, all male, adult students, between 18 and 28 years (M = 21.170, SD = 2.444) were tested. The inclusion criteria to participate in the study were: level of

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attention in D2 test (Welter, 2000) above the 25th percentile and level of intelligence above 25th percentile, this was measured by the Raven's Progressive Matrices – General Scale (Raven, 2000). Exclusion criteria were presence of vision problems, history of psychiatric problems and learning disorders, verified by a prior individual interview. This research project was approved by Institutional Human Experimentation Committee of authors University (CEP/UPM 1153/08/2009). Written consent was obtained from all participants after an explanation of the experimental procedure was done.

Reading task

The stimuli were composed of 6 texts divided into three groups according to the theme. Group 1 consisted of 2 texts addressing everyday situations; group 2 consisted of 2 texts obtained from textbooks; and, finally, group 3 consisted of 2 texts extracted from newspapers. In each text group, the first text was classified as simple and the second text was classified as complex. This classification was established by the function of word frequency occurrences in Brazilian Portuguese. The degree of complexity was controlled according to the frequency of occurrences of the words in the texts. Thus, in each group, the degree of complexity of the first text was less than the second text. Furthermore, the number of words and rows of text ranged as follows: group 1 had texts with 141 and 126 words, with 9 rows each; group 2 had texts with 152 and 126 words, with 11 rows each; group 3 had texts with 201 and 176 words, with 13 and 14 rows. Texts were presented in bitmap format files (BMP) with a resolution of 800 x 600 pixels. The font used was Courier New, bold black type, size 18 in white background.

Equipment

The equipment used to record eye movements was the Tobii 1750, developed by Tobii® Technology Inc. Tobii records binocular eyes movements and pupil dilation based on corneal reflex. It consists of a 17-inch TFT, 1280 x 1024 pixels, monitor with two high-resolution cameras on its underside. Alongside this is the infrared ray emitting diodes (Near Infra-Red Light-Emitting Diode) situated in the direction of both eyes with a high resolution camera embedded in its bottom. The corneal reflex is used to capture the process of eye movements and pupil dilation, with coordinates recorded by video at a 60 Hz frequency. Eye movements are registered on ClearView® software, operating in Windows® XT system. The Clear View software generates eye position (coordinates axes x and y), pupil diameter, 3D eye position and a brief analysis of saccades and fixations.

Procedure

Participants were tested in a session lasting one hour on average. At the beginning of the session, the Raven's Progressive Matrices Test and D2 Test for assessing fluid

intelligence and concentrated attention, respectively, were applied. Thereafter, the assessment of reading and recording eye movements was carried out. The analysis of the scores obtained by the participants in the Raven's Progressive Matrices Test and the Concentrated Attention Test D2 was performed according to the standardized testings of the Brazilian population. Results indicated that all participants had attention levels above the 25th percentile and therefore had normal levels of attention. The assessment of the level of intelligence indicates that no participants had scores below the 25th percentile. Therefore, the criteria for inclusions within the study were met.

For eye movements data collection, participants were seated at a distance of 60 cm from the computer screen. Participants viewed the stimuli binocularly with approximately 2.5 letters per degree of visual angle on a 17-inches monitor. The equipment was calibrated to each subject's function of pupil size and curvature of the cornea. A forehead support was used to minimize head movements. Texts were read aloud by participants and comprehension was assessed through three questions regarding the content of the text, asked immediately after reading. Texts were presented in the same sequence for all participants. Vocalizations were recorded in the computer, and the parameters of eye movements were recorded.

Data analysis

We analyzed monocular left eye movements, once both eyes tended to converge fixations during reading. To analyze behavioral and eye movements measures, statistical program SPSS ® 18.0 for Window ® was used. The level of significance was 5%. Performing time of reading texts was analyzed. As the texts had different sizes, we calculated the average reading time by word. Thus, it was possible to compare reading time between texts. Repeated measures Anovas and effect sizes (Cohen's d) were computed to compare reading average time by word and by text, number of fixations by word and by text and, finally, number of regressive saccades. All measures were analyzed according to complexity and theme of the text.

Results

Results show that the average time by word read varied according to the text complexity ($F [1.23] = 43.607$, $p < 0.001$) and theme ($F [2.22] = 187.433$, $p < 0.001$). Simple texts were read faster than complex texts in all groups (Group 1 Cohen's $d = 0.43$; Group 2 Cohen's $d = 0.23$; Group 3 Cohen's $d = 0.90$). LSD Post hoc analysis indicated that average time of words read in the texts with Group 1 was significantly lower than with Group 2 ($p < 0.001$) and Group 3 ($p < 0.001$), but no difference was found between Group 2 and 3 ($p < 0.105$). GLM analysis indicated the interaction effect between theme and complexity ($F [2.22] = 11.105$, $p < 0.001$). Table 1 shows the values of descriptive statistics for average time by words read related to theme and complexity of texts.

Table 1. Reading time means by text (seconds) and word (milliseconds)

		Type			
		Simple	Complex	$F_{[1,23]}$	p
Group 1 Everyday Situations	Mean/Text (SD)	44.84 (±0.37)	41.69 (± 0.41)	31.859	0.000
	Mean/word (SD)	318.06 (±26.48)	330.92 (± 32.95)	8.765	0.007
Group 2 Textbooks	Mean/Text (SD)	59.956 (±0.57)	50.72 (± 0.41)	198.162	0.000
	Mean/word (SD)	394.45 (±37.54)	402.56 (± 32.94)	224.761	0.000
Group 3 Newspaper	Mean/Text (SD)	78.556 (±0.75)	75.18 (± 0.750)	12.105	0.002
	Mean/word (SD)	390.82 (±37.70)	427.20 (± 42.63)	48.142	0.000

Source: Produced by authors.

The number of fixations during reading of the texts was analyzed. We calculated a number of fixations on words, as the texts had different sizes. Thus, it was possible to compare these measures.

Table 2 shows the values of descriptive statistics for the average number of fixations in the reading of words in relation to the theme of each text.

Table 2. Fixations means by text and word

		Type			
		Simple	Complex	$F_{[1,23]}$	p
Group 1 Everyday Situations	Mean/Text (SD)	140.75 (± 19.46)	131.79 (± 18.14)	13.275	0.001
	Mean/word (SD)	0.99 (± 0.13)	1.04 (± 0.14)	6.748	0.016
Group 2 Textbooks	Mean/Text (SD)	184.04 (± 21.62)	152.75 (± 18.25)	114.635	0.000
	Mean/word (SD)	1.210 (± 0.14)	1.212 (± 0.14)	0.005	0.942
Group 3 Newspaper	Mean/Text (SD)	232.00 (± 37.57)	212.33 (± 28.68)	15.134	0.001
	Mean/word (SD)	1.154 (± 0.18)	1.206 (± 0.16)	4.173	0.053

Source: Produced by authors.

Results show that the average number of fixations in word reading increased with the function of the text complexity ($F [1.23] = 8.134$, $p < 0.010$) and theme ($F [2.22] = 83.144$, $p < 0.000$). In simple texts, the number of fixations was lower than in complex texts (Group 1 Cohen's $d = 0.34$). LSD Post hoc analyses indicated that the average fixations per word in Group 1 was significantly lower than in Group 2 ($p < 0.001$) and Group 3 ($p < 0.001$), but no difference was found between Group 2 and 3 ($p = 0.237$). The GLM analysis indicated no interaction effect between theme and complexity

(F [2.22] = 1.841, p < 0.183). In order to analyze regressive saccades, regressions with and between words were calculated.

Table 3 presents the descriptive statistics.

Table 3. Regressive saccades means by text and word

		Type			
		Simple	Complex	$F_{[1,23]}$	p
Group 1 Everyday Situations	Mean/Text (SD)	15.74 (± 5.84)	16.59 (± 4.44)	259.121	0.000
	Mean/word (SD)	3.57 (± 2.53)	4.885 (± 1.79)	130.811	0.000
Group 2 Textbooks	Mean/Text (SD)	4.55 (± 2.70)	17.24(± 5.9)	4.454	0.046
	Mean/word (SD)	6.48 (±3.94)	19.87 (± 5.72)	6.375	0.019
Group 3 Newspaper	Mean/Text (SD)	18.12 (± 18.12)	18.12 (± 18.12)	2.188	0.153
	Mean/word (SD)	5.69 (± 4.269)	8.00 (± 5.74)	6.447	0.018

Source: Produced by authors.

Anovas indicated that the average number of regressive saccades during reading increased as a function of the text complexity (F [1.23] = 4.442, p < 0.047) and the theme (F [2.22] = 8.162, p < 0.003). The participants made less regressive saccades in simple texts than in complex texts (Group 2 Cohen's d = 0.45). LSD Post hoc analyses indicated that the number of regressive saccades in Group 1 was significantly lower than in Group 2 (p < 0.003) and Group 3 (p < 0.034), but no differences were found between Group 2 and 3 (p = 0.237). The GLM analysis indicated interaction effects between theme and complexity (F [2.22] = 4.792, p < 0.020).

Finally, d's Cohen comparison between text themes is presented in Table 4.

Table 4. Effect size by text theme

	Type	Cohen's d time reading	Cohen's d number fixations	Cohen's d regressive saccades
Group 1 X 2	Simple	2.35*	1.52*	0.12
	Complex	2.17*	1.15*	0.71*
Group 1 X 3	Simple	2.23*	0.95*	0.27
	Complex	2.53*	1.04*	0.52*
Group 2 X 3	Simple	0.10	0.34*	0.14
	Complex	0.65*	0.04	0.06

* Cohen's d > 0.30.

Source: Produced by authors.

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Discussion

The present study verified that the average of reading time, the number of fixations and the number of regressive saccades by word varied according to complexity and theme of the texts presented. The effects found in the average reading time and the number of ocular fixations by word related to complexity and theme was corroborated by Yokomizo *et al*. (2008). According to this study, during the reading of simple texts, the amount of information that must be stored is less when compared with a complex text. The less information stored in working memory allows better articulation between them, generating easier and deeper comprehension. The greater the amount of information to store and manipulate, the greater the time spent on reading, with simultaneous increase in the number of fixations. At the same time, Miyata *et al*. (2012) found correlations between reading speed, accuracy and measures of eye movements, being that fast readers showed lower fixations and larger saccades than average and slow readers.

Analyzing reading time and number of fixations differences between themes of the text found that the greater average of these measures in complex texts can be explained by the fact that more complex texts present more words with low frequency of occurrence in Brazilian Portuguese. Yokomizo *et al*. (2008) also observed a larger number of fixations in words of low frequency. Apart from this variable, the level of prior knowledge on the subject read is another factor that facilitates or denies the processing of reading. Jian and Ko (2012) found in a study of reading texts and recordings of eye movements that adults with higher levels of qualifications in an area of knowledge had the lowest rates of regressive saccades in unknown and common words as well as less time spent rereading information. Thus, in general, the participants of this study had a higher knowledge domain and familiarity with everyday situations than in journalistic texts. Furthermore, in order to obtain reading comprehension, word recognition abilities are not enough. Beyond these skills, readers need to perform inferences by the domain of the text and have good memory skills, which together contribute to building a representation of macrostructural text (Salles & Parente, 2002; Navas, Pinto, & Delissa, 2009).

According to Navas *et al*. (2009), the automated and rapid identification of words facilitates the allocation of attentional and complex cognitive resources used to perform operations of parsing and semantic integration. Thereby, leading to greater understanding of sentences and the text as a whole. In reading familiar and high frequency words the lexical route is used, with direct access to graphical, phonological and semantic word representations. During the reading of low frequency words, the phonological route is used, which requires greater recruitment of working memory for decoding and later access to the meaning (Capovilla & Capovilla, 2002). The results must be interpreted, taking into account that the theme of text and complexity are not completely decoupled. Thus, longer texts tend to be harder than the shorter texts. Even if the frequency, the regularity, and the length of the words are controlled.

The reading of texts of different themes demand different efforts to access working memory and therefore a larger amount of information must be processed and stored.

Our study found a larger number of regressive saccades in higher complex texts, as well as what Yokomizo *et al*. (2008) observed. Blythe *et al*. (2009), studying visual information capture during fixations in reading for adults, found a reduced average of regressive saccades in text reading, since the material presented was not complex. In an experiment with more complex texts, Liversedge *et al*. (2004) related that 20% of adults made regressive saccades in texts with normal presentation. Furthermore, the large number of fixations observed in complex texts relates closely to the higher occurrence of regressive saccades. These analyses of regressive saccades in Brazilian Portuguese texts may also show similar results to that observed in other languages (Rayner, 1998).

Monocular analysis may thus potentially enable further related investigations with binocular eye movements in normal readers and individuals with developmental dyslexia. Dyslexic adults demonstrate twice as much eye fixations in sentence reading, reduced frequency of unread words and larger number of fixations on the same word when compared to normal readers (Hawelka, Gagl & Wimmer, 2010). In that sense, we should expect higher number of fixations and regressive saccades in dyslexic people, as well as lower reading times and poorer comprehension skills when compared to normal readers.

According to Liversedge *et al*. (2004), both eyes are typically converging to the same direction, but this convergence doesn't eliminate binocular disparity. Moreover, using binocular measures allows studying the intra-fixation movement that seeks to reduce the disparity (Inhoff *et al*., 2008). Moreover, Schotter *et al*. (2012) reports that binocular eye control during reading is important for visual information processing and consequently for word comprehension and predictability in texts. In order to extend reading comprehension of texts, binocular system must fuse projected images in each retina to create a clear perception of sentences, and these images could be directed to the same target or to different parts of words.

The study has some limitations related to texts linguistic proprieties. The authors defined the text complexity unless in function of word frequency in Portuguese, without considering phrasal syntactic structure. There is not a text data base that can be used in order to select this kind of stimuli for cognitive experiments. The study did not also controlled participant's text comprehension, which could be done with informative and interpretative questions after reading. We suggest further studies that correlate more behavioral reading measures with eye movement data. Other suggestion is related to binocular eye movement analysis. Even if other experiments did not showed significant differences between left and right eye movements pattern during word reading (Inhoff *et al*., 2008), is important to conduce a binocular analysis once new technology in eye gaze equipment are being developed and allows more accurate comprehension.

The present study showed that the pattern of eye movements of students varied according to complexity and theme. In summary, the present data provides a characterization of eye movement patterns found in adults students during reading of simple and complex texts and in texts related to everyday situations, as well as textbooks and newspapers. Average reading time by word, number of ocular fixations and number of regressive saccades varied according to complexity and theme of texts. The results reported in this study may eventually be used to compare performance in reading comprehension and the pattern of eye movements of adults with and without developmental dyslexia.

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