Original Article

Reading eye movements among homonymous hemianopia

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Purpose: To measure the reading eye movement's parameters and quantify the oculomotor dysfunction among subjects with homonymous hemianopia compared to age-matched controls using ReadAlyzer. **Methods:** This was a prospective study carried out in the neuro-optometry clinic of a tertiary eye care hospital in South India, from October 2018 to Janurary 2019. Fifty consecutive patients diagnosed with homonymous hemianopia were enrolled in the study after obtaining their written informed consent. Reading eye movements were measured using ReadAlyzer in patients with homonymous hemianopia and age-matched controls. Reading eye movement parameters were represented in median [interquartile range (IQR)]. **Results:** Subjects with homonymous hemianopia showed increased number of fixations/100 words- median (IQR) [175 (80–270)] compared to controls [91 (52.5–127.5)]; increased number of regressions/100 words [33 (−13–79)] compared to controls [18 (−10–46)]; and reduced reading rate [93 (46–140) words/min] compared to controls [186 (144–228) words/min] (Mann–Whitney *U* test, $P \leq 0.05$). Similar trend was observed for grade level equivalent 2 (0–4) and regression to fixation ratio 15 (1–29) compared to controls [grade equivalent 7 (3–11) and regression to fixation ratio 11 (−2–24)] (Mann–Whitney *U* test, $P \leq 0.005$). **Conclusion:** Reading eye movements assessed using ReadAlyzer are found to be significantly impaired among homonymous hemianopias compared to age-matched controls (Mann–Whitney *U* test, $P \leq 0.05$).

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Cerebrovascular accident is found to be the most common cause in 70% of patients with homonymous hemianopia (HH), a visual field disorder occurring due to post-chiasmal damage secondary to ischemia in the lateral geniculate body, optic radiations, or the occipital lobe and can manifest as sectoranopias, quadrantanopias, or hemianopias, either congruous or incongruous.[1] A global damage to the neural network of the occulomotor system an acquired brain injury leads to reading dysfunction.

Reading is one of the complex skills which is disrupted at the visual and phonological stages post-cerebrovascular accident. Impaired gaze holding, saccades, and impaired smooth pursuits affect various levels of visual attention. Patients can also develop hemianopic dyslexia if not rehabilitated at the correct time. Reading becomes so laborious that many patients give up recreational reading and if reading is an occupation, then this becomes an employment risk.

The accurate, rhythmical, and spontaneously executed sequences of the eye movements with fixational pauses are essential for normal reading.[2] Following spatially distributed visual information along with maintaining comprehension requires both eyes to follow a typical scan path across the text, that is, from left to right and from top to bottom. Plotting the eye position against time reveals a staircase pattern as saccadic eye movements regularly alternate with periods of fixations. About 10%–15% of our reading saccades are regressive. Toward the end of the line of text, a large right to left anti-saccade eye movement is made close to the beginning of the next line.

Eye movements during reading are systematically influenced by visual and lexical characteristics of the text information extracted during a fixation.[3] The region of effective processing during reading, the perceptual span, extends about three or four characters to the left and up to 15 characters to the right of fixation. As 1° of visual angle encompasses about three characters for most normal tests, these values are equivalent to 1.3° to the left and 5° to the right of fixation.[3-6]

There exists functional plasticity of the visual, attentional, and oculomotor systems involved in text processing. Poor eye movements, reduced visual fields, and poor reading ability together contribute to prolonged fixation, reduced saccadic amplitudes, and increased regressive saccades. Foveal processing of fixated words enables word identification. Fixation duration is influenced by factors such as word frequency, predictability, and age of acquisition.[3]

ReadAlyzer is an objective eye movement recording device that tracks the reading eye movements. Studies have shown

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impaired eye movement parameters among various visual field defects.[7,8] Hence, it is necessary to understand the eye movement parameters among HH patients.

Methods

A prospective comparative study was conducted between October 2018 and January 2019 in the neuro-optometry clinic of a tertiary eye care center in South India. The study adhered to the tenets of the Declaration of Helsinki, and the methodology was reviewed and accepted by the Institutional Review Board and the Medical Ethics Committee.

A total of 50 subjects with HH and 50 controls, considering a 1:1 ratio between cases and controls, were included in the study. Subjects diagnosed with HH based on the Humphrey visual field test 30-2 were referred by a neuro-ophthalmologist. Subjects with HH aged between 18 and 50 years with best corrected visual acuity of 20/60 for distance and N6 for near, who had an onset of 6 months to 12 months were recruited for the study. All subjects with multiple disabilities, seizures, or any retinal pathology were excluded from the study. Age-matched controls with normal ocular health were recruited through voluntary participation from those who visited the clinic during the study duration. A duly signed, written informed consent was obtained from all the study participants.

Testing protocol

All subjects received a comprehensive eye examination, which included history taking, refraction, sensory and motor evaluation, followed by a detailed neuro-optometry evaluation.

Reading eye movement assessment

The developmental eye movement (DEM) test was used to understand the horizontal and vertical time, based on which the oculomotor dysfunction (OMD) was classified based on the ratio score. Reading eye movements were assessed objectively using ReadAlyzer (Compevo AB, Stockholm, Sweden). ReadAlyzer consists of infrared emitters and detectors mounted in safety goggles. It can determine the eye positions by sensing several infrared reflections from the cornea. The measuring speed of the instrument is 60 Hz. The software automatically compensates for head movements.[9-11] The near interpupillary distance was measured with a penlight and an interpupillary distance scale. The subjects wore eye movement goggles, and the near interpupillary distance was adjusted. The test paragraphs were placed at 40 cm with the near correction on. In addition, proficiency with the English language was asked as they were given to read an English paragraph.

Eye movements were recorded for cases and controls on the computer screen connected to the ReadAlyzer, while the subject read a short English paragraph aloud. The highest grade level paragraph (Grade 10) was used for measurement. There were five different passages in Grade 10, which is equivalent to the font Times New Roman and a size of 12 points. The subject read one practice paragraph, following which two trials were made with different passages. The second trial was taken as the final reading to assure a stable baseline measurement.[12] A comprehension test comprising 10 "Yes" or "No" responses was also administered to confirm the subject's comprehension. After the recording, the system performed an automatic analysis and provided the report [Fig 1].

Reading parameters included fixations per 100 words (progressive saccades); regressions per 100 words (backward saccades); fixation duration (seconds), which is the average length of time (in parts of a second) the eyes paused or fixated; reading rate (words per minute); grade level equivalent (GLE), which is the weighted average of the grade levels for the subject's fixations, regressions, and reading rate, yielding a combined grade level; and comprehension (%), which is the percentage of the correct answers. There were also large right-to-left oblique saccadic eye movements called saccades in return sweep, which occur when one must shift to the next line of print [Fig. 1].[12]

Results were analyzed using Statistical Package for Social Sciences (SPSS) (Version 17.0; SPSS Inc, Chicago, IL, USA). The data set did not follow normality (Shapiro–Wilk test), hence appropriate coding was generated for categorical variables. Mann–Whitney *U* test was used to compare the values between hemianopic subjects and healthy controls. Spearman's correlation was used to understand the relationship between the variables. The median and interquartile range (IQR) were used to represent the data. The alpha error was set as 5%.

Results

Results from 50 cases and 50 controls were included for statistical analysis. The mean age of cases and controls was 46 and 41 years, respectively, with a male to female ratio of 6:1. Twenty- (42%) cases were diagnosed to have right HH (RHH) and 29 (58%) cases with left HH (LHH).

In the majority of cases (70%), the etiology was found to be cerebrovascular accident, whereas 20% presented with traumatic brain injury and 10% with tumor excision [Fig. 2]. In the total sample, 44 (88%) out of 50 subjects presented to the clinic with the complaint of difficulty in reading, among which 17 (80%) cases were RHH cases and 27 (93%) cases were LHH cases.

DEM testing was done for the cases to grade OMD. The median (IQR) scores are presented in Table 1. Based on the vertical score, horizontal score, and ratio score, OMD was graded as OMD type I, II, III, and IV. Thirty-five (70%) subjects were diagnosed with OMD type IV, eight (16%) with OMD type III, seven (14%) with OMD type II, and two (4%) with OMD type I [Fig. 3].

The results of the reading eye movement assessment using ReadAlyzer were compared between cases (HH) and age-matched controls [Table 2]. Subjects with HH showed increased number of fixations/100 words- median (IQR) [175 (80–270)] compared to controls [91 (52.5–127.5)]. An increased number of regressions/100 words was noted among cases [33 (−13–79)] compared to

Table 1: Developmental eye movement

DEM (*n*=50)	Median (IQR)
Vertical score (Test A + Test B)	35 (21.75–48.25)
Adjusted horizontal score	43.5 (25.50–61.50)
Ratio score (adjusted horizontal time/vertical time)	2.23 (1.96–2.50)

DEM=developmental eye movement, IQR=interquartile range

Table 2: ReadAlyzer parameters among cases and controls

Eye movement parameters	Cases Median (IQR)	Controls Median (IQR)	*P*
Fixations/100 words	175 (80–270)	91 (52.5–127.5)	$P \leq 0.05$
Regressions/100 words	-33 (-13–79)	-18 (-10–46)	$P \leq 0.05$
Fixation duration (sec)	0.00	0.45 (0.15–0.75)	$P \leq 0.05$
Reading speed (words/min)	93 (46–140)	186 (144–228)	$P \leq 0.05$
Grade equivalent level	2 (0–4)	7 (3–11)	$P \leq 0.05$
Regression/fixation ratio	15 (1–29)	11 (-2–24)	$P > 0.05$
Comprehension (percentage)	80 (45–115)	92 (64–120)	$P \leq 0.05$

IQR=interquartile range

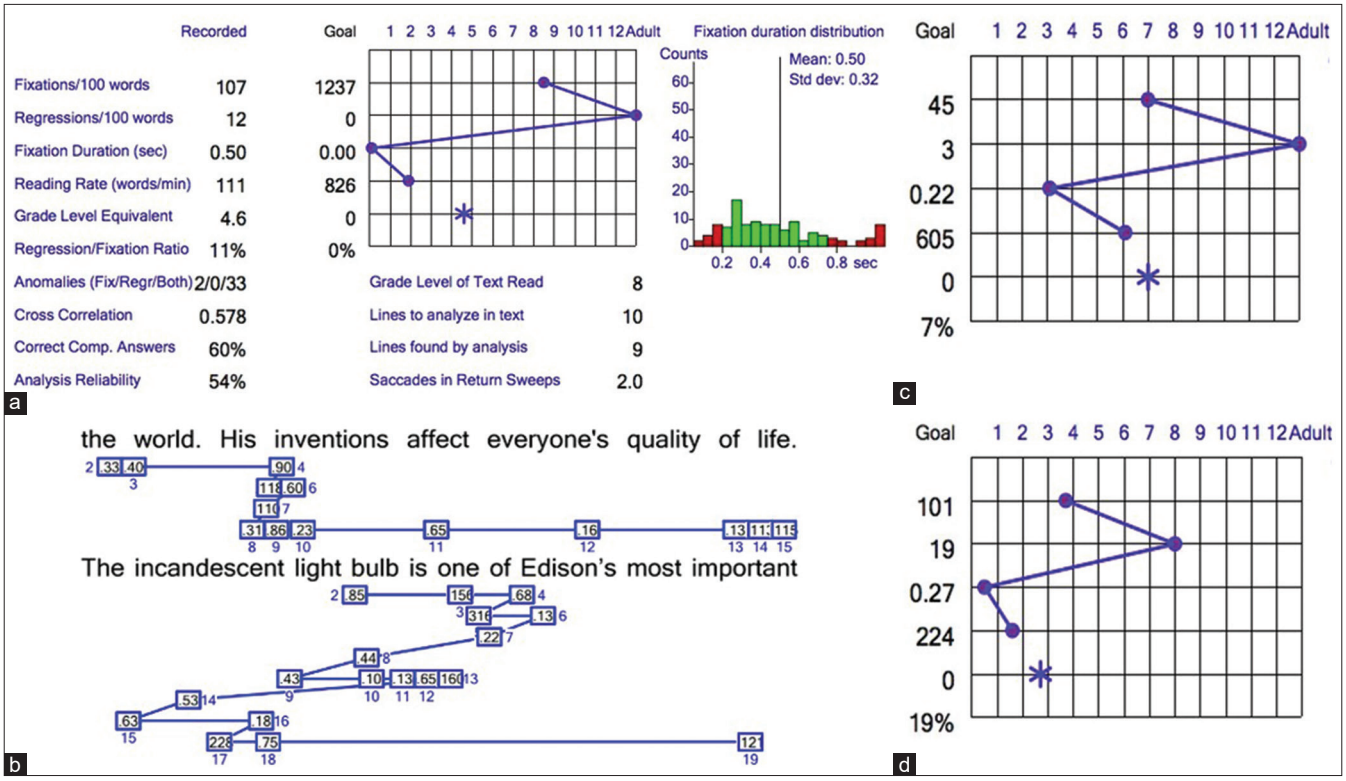

Figure 1: (a) Output sheet. (b). Sentence details (fixations and regressions). (c). Graph pattern among RHH. (d) Graph pattern among LHH. LHH = left homonymous hemianopia, RHH = right homonymous hemianopia

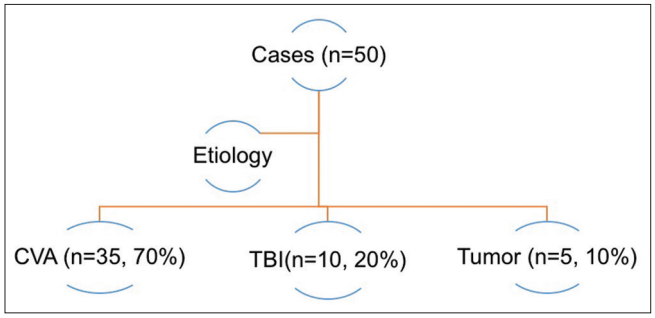

Figure 2: Oculomotor dysfunction among homonymous hemianopia

controls [18 (–10–46)], and reduced reading rate was noted among cases [93 (46–140) words/min] compared to controls [186 (144–228) words/min] (Mann–Whitney *U* test, $P \leq 0.05$). Similar trend was observed for GLE [2 (0–4)] and regression to fixation ratio [15 (1–29)] compared to controls – grade equivalent 7 (3–11) and regression to fixation ratio 11 (–2–24) (Mann–Whitney *U* test, $P \leq 0.05$).

The relationship between the number of fixations/100 words and reading rate in HH subjects showed a significantly strong negative correlation [Fig. 4] (Spearman's correlation). To understand the reading eye movements, specifically the reading speed (words/min), based on the side of visual field defect, a comparison was done between RHH and LHH and we found that RHH subjects had a prolonged reading speed [78 (36–120)] compared to subjects with LHH [102 (68–136)] (Mann–Whitney *U* test, $P \leq 0.05$) [Fig. 5].

A detailed analysis of the reading eye movement among subjects with RHH and LHH presented in Table 3 reports an increased number of fixations/100 words, regressions/100 words [28 (2–56)], and reduced reading rate (words/min) of 92 (44–128) [represented in median (IQR), $P \leq 0.05$].

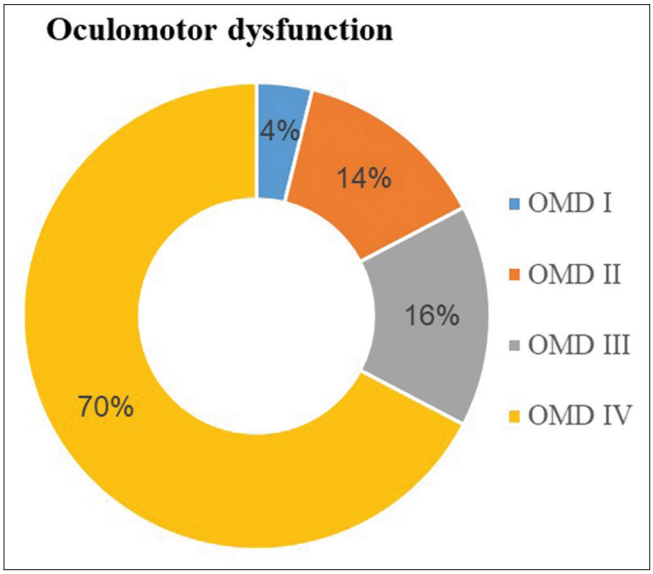

Figure 3: Correlation between the fixations and reading speed

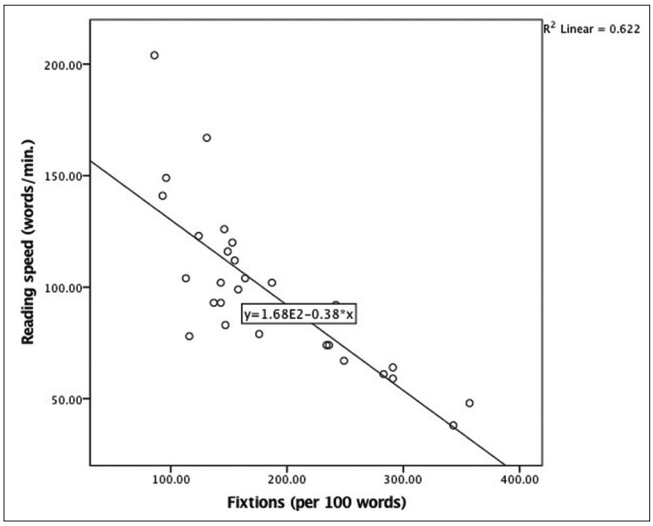

Figure 4: Different etiologies among homonymous hemianopia

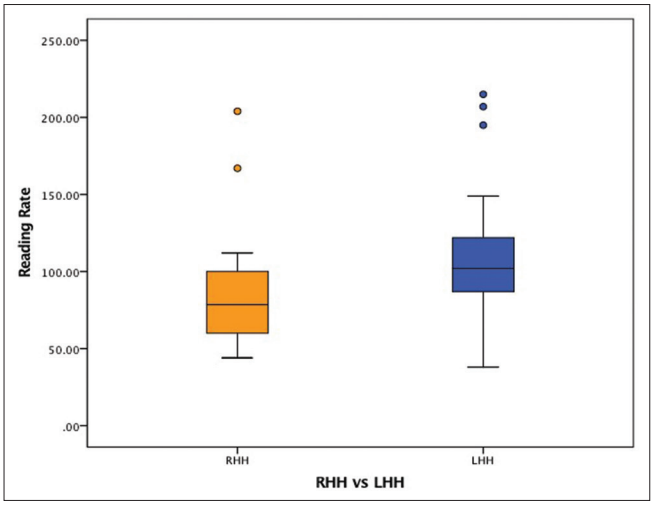

Figure 5: Reading speed among RHH and LHH. LHH = left homonymous hemianopia, RHH = right homonymous hemianopia

Table 3: ReadAlyzer parameters among RHH and LHH

Eye movement parameters	RHH Median (IQR)	LHH Median (IQR)	*P*
Fixations/100 words	74 (56.7–91.5)	108 (90.5–127.5)	$P \leq 0.05$
Regressions/100 words	-13 (–9–35)	–4 (-10–2)	$P > 0.05$
Fixation duration (sec)	0.00	0.15 (0.05–0.19)	$P > 0.05$

LHH=left homonymous hemianopia, IQR=interquartile range, RHH=right homonymous hemianopia

Discussion

This study focuses on the reading eye movements among HH patients compared to age-matched controls. Reading performance shows a markdown in patients with HH due to their poor tracking levels. To assess this, the objective method of reading eye movements was adopted in this study.

DEM testing was used to determine the automaticity and the reading ability using a vertical and horizontal spatial array of numbers. The ratio score represented a measure to evaluate the horizontal and vertical time simultaneously. The majority of the hemianopic subjects in our study population were diagnosed with type IV OMD. This elicited that the vertical time, horizontal time, and ratio scores were all abnormal, which represents the deficiencies in both automaticity and oculomotor skills, hence disrupting eye movements. This evaluation provides insight into the functional integrity of the brain. There were significantly disrupted saccades and pursuits among hemianopic cases. Reduced visual fields, poor eye movements, and perceptual difficulties together contribute to poor reading ability.[13] The accuracy and ability to make a saccadic eye movement or a smooth pursuit were hampered.

We evaluated the reading eye movements using the ReadAlyzer, a detailed measure of increased fixations, and the regressions were obtained. The prolonged fixations and the regressions together contribute to the reduced reading speed among hemianopic patients. Right hemianopic patients show poor reading speed compared to the left hemianopic patients. Similar findings were reported by Kerkhoff G, Trauzettel and Ong, *et al* in 1970.[14-16] The fixations are significantly different from normal ones in the spatial locations; in addition, the hemianopic population has a strategic fixation pattern that is distinct from the healthy controls.[17] The scan paths studied previously among hemianopes explain the higher number of fixations of shorter duration and longer saccadic amplitudes due to the visual field defect, which significantly affects the eye movements.

Reading eye movement provides essential information about the visual perceptual field and learning effects, which are helpful in rehabilitation. Vision training can improve reading ability by decreasing errors and improving reading speed. Neuro-optometric visual rehabilitation helps in improvising eye and head scanning, thus improving visual attention, and increasing the number and amplitude of saccades into the impaired hemifield. Read-Write, NeuroCoach, and Sanet Vision Integrator are available software that are used to teach systematic scanning tactics in more organized and efficient search times.[18] Visual rehabilitation and its impact on the quality of life needs further exploration.

Conclusion

Reading eye movement parameters are prolonged in subjects with HH compared to healthy controls. These findings along with intensive neuro-optometric evaluation help clinicians to evaluate reading deficits and to observe the improvement. These findings also serve as baseline measurements to decide upon neuro-optometric vision therapy and improve the quality of life among such individuals.

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