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Effect of Saccadic Movements and Visual-Attentional Training on Reading Task in Age-Related Macular Degeneration Subject

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Abstract

Purpose: To study the impact of AMD on reading, and to prove the effect of saccadic movements and visual-attentional training on reading capability in AMD subjects. We hypothesized that AMD subjects had abnormal reading task performances, and that a specific training could change oculomotor pattern during reading in AMD subjects.

Methods: Two groups participated to visual-attentional training: 20 AMD subjects (mean age: 72.6 ± 0.9 years) and 10 healthy age-matched control subjects (mean age: 69.3 ± 1.1 years). Reading performances were recorded before and after horizontal saccadic movements and visual-attentional training (Metrisquare®) with the Mobile Eye Tracker (Mobile EBT®). We analyzed the duration of fixations and the number and the amplitude of pro- and backward saccades during reading a text.

Results: Before training, the fixation duration in AMD subjects was significantly longer compared to healthy elderly. The number and the amplitude of prosaccades and backward saccades were similar in AMD subjects and in healthy elderly. After training, AMD subjects normalized the fixation duration.

Conclusions: Longer fixation duration in AMD subjects could be due to their abnormal visual input (retinal anatomic lesions). A short visual-attentional training could be able to develop in AMD subject's adaptive mechanisms leading to change oculomotor pattern during reading. Additional studies will be necessary to explore the effect over time of visual attentional training in these subjects.

Keywords: AMD; Elderly; Fixation; Reading; Saccades; Visual-attentional training

Highlights

- AMD subjects have longer fixation duration than healthy elderly.
- The numbers of pro- and back saccades are similar between AMD subjects and elderly.
- A visual-attentional training period normalizes fixation duration in AMD subjects.
- AMD subjects develop rapidly adaptive mechanisms.

Introduction

Reading is a process requiring multiple psychophysical and cognitive mechanisms: sensorial perception, eye movements, linguistic and semantic capacities. When one of these processes is disturbed, reading is defective. During reading, the central nervous system has to converge the two eyes to the distance of the text and to coordinate the two eyes in the horizontal direction of the text (to the right) by making several saccades and fixations. Saccades allow to bring the eyes on the words and during fixation period identification, memorization and comprehension of the word occur [1]. In the literature it has been showed that reading capabilities change with aging. Lott, et al. (2001) compared the impact of vision characteristics during a reading task in 545 healthy elderly and evaluated the reading performances using an oral test of reading at near vision, without using any objective eye movement recording [2]. The authors showed a decrease of the reading rate (total number of correct items/time) for the older group of subjects only (85+), and a correlation between reading rate and respectively the visual acuity and the contrast sensitivity for all subjects tested, and they suggested that the best predictor of reading capability in elderly was the contrast acuity and not the visual acuity. In addition, Rayner, et al. (2009) reported that the perceptual span named also visual span (corresponding to the section of text from which a subject can extract useful information from reading) was reduced in older subjects, leading to do smaller rightward saccades during reading in older subjects [3]. This result was confirmed by Liu, et al. (2017), which suggested that the slower reading in older subjects could be due to shrinkage of the visual span and to enlargement of crowding zone in these patients [4]. Moreover, several studies explored eye movement performance in elderly with an eye-tracker (see [5]). Indeed, it has been showed that older subjects tend to have longer and more frequent fixations during reading with respect to young adults (for a recent review, see [6]). Recently, Choi, et al. (2017) compared reading capabilities in 34 young adults (19-25) and 24 older adults (67-80) by recording objectively eye movements [7]. They found that elderly had longer fixation durations, made more fixations per sentence, and showed longer reading times compared to young adults.

Furthermore, they reported also that there were no age differences in skipping rates in contrast to previous studies from Rayner's group [3,8]. In elderly subjects, some pathology could generate visual disabilities, which affect reading performances like Age-Related Macular Degeneration (AMD). AMD is the first cause of visual impairment after fifty years old in developed countries that should affect 288 million of elderly in 2040 [9,10]. It is characterized by progressive degeneration of photoreceptors in macula (central retina) and AMD subjects lose visual acuity and autonomy progressively [11]. Because there is no curative treatment, one of the solutions to slow down their functional disability, is the development of low-vision rehabilitation [12]. In this pathology reading is the most common disability [13,14]. At our knowledge, a few research studies explored eye movements during reading task in AMD subjects. Calabrèse, et al. (2014), using an eye tracker, explored the reading characteristics in 35 advanced level AMD subjects [15]. They showed a negative correlation between the reading speed and the duration of fixations. In another study, Crossland and Rubin (2006) measured, with an SMI eye tracker the reading performances in 18 macular disease subjects (mean age: 65.1 years) compared to 7 controls (mean age: 55.4 years) on two sessions separated by up to one year [16]. Only the worse eye was recorded for each subject. The authors found that AMD subjects had smaller saccade amplitude than healthy elderly during reading. Moreover, a correlation between the number of forwards saccades and reading speed in AMD subjects was also observed. Interestingly after the second visit, some AMD subjects had duplicated reading speed (with respect to their previous examination) and the amplitude of saccades increased significantly. Then AMD subjects had an adaptation capacity to improve their reading performances despite their anatomic retinal lesion. Moreover, Cheong, et al. (2008) confirmed the reduction of visual span in AMD subjects compared to age-matched controls [17].

In current practice, low-vision aids (for example magnification requirement, video magnifier, etc) were suggested by medical clinicians to AMD subjects in order to optimize their reading abilities [18]. For instance, Nguyen, et al. (2009) evaluated, in a retrospective study, the reading ability before and after providing appropriate magnification for low vision aids in 530 AMD subjects (age mean: 82 years) [19]. The authors showed an improvement of reading ability (increased reading speed) only by using low vision aids and proposed to develop their utilization in order to limit AMD subjects' disability. Moreover, for several years, a few researchers developed low-vision rehabilitation program in maculopathy subjects to improve their reading performances [20]. Oculomotor training has been also tested in AMD subject in order to improve their reading capabilities. Seiple, et al. (2005) studied the impact of oculomotor training on the reading speed in 16 AMD subjects (65-87), without comparison with healthy age-matched elderly [21]. The training program (eight weekly sessions between one and two hours) was composed of three exercises of horizontal saccades with an increasing difficulty: different types of stimuli were use as single letters, pairs of letters and three-letter words. The training was performed monocularly, with the better eye viewing, and reading task was recorded before and after the training with an eye-tracker system with a low simple frequency (of 60 Hz only). The results showed that the reading speed increased after the training program in AMD subjects. They suggested that oculomotor training can improve reading speed in AMD subjects; note however, that these authors did not explain the mechanisms underlying such improvement. Later on, Seiple, et al. (2011) quantified the effects of different types of training (six weekly sessions of two hours) on reading performances in 30 AMD subjects (54-89) without a group of control subjects for comparison [22]. Three training types were tested for each AMD subjects: *Preferred Retinal Locus* training consisting in learning to use for reading the better functional zone of the retina; *Oculomotor training* consisting in making visually guided saccades; and *Reading* consisting in several reading exercises. A reading task was performed before and after each training program in order to evaluate possible reading improvement of the subjects by using an eye tracker. The authors showed a significant increase in reading speed only for oculomotor training type while the other two training types were useful to improve visual capabilities only. Coco-Martin, et al. (2013) evaluated the benefit of a reading training on reading performances (without objective eye movements recording) and on the quality of life (evaluated by a questionnaire) in 41 AMD subjects (mean age: 76.1 years) without comparison with control subjects [23]. The training was composed by four sessions over six weeks done in the laboratory as well as thirteen sessions made at home, and the difficulty of reading training increased progressively in term of type of font and font size. These authors showed a constant increase of reading speed between each session, and a correlation between the improvement of reading performances and the quality of life felt by subjects, suggesting that a progressive training, adapted to each subject, could be important to optimize the benefit of the training. Importantly, Kosengarth, et al. (2013) using functional MRI reported modifications of brain activation (that is an increase of gray and white matter density in cerebellum), and improvements of reading speed during oculomotor training in AMD subjects [24], suggesting that adaptive mechanism take place in these kinds of subjects. In the present study we wonder to explore further reading performance in AMD subjects and the eventual benefit of a visual-attentional training by recording eye movements before and after training with a system with higher simple frequency (300 Hz). Finally, these results were compared with those obtained by a healthy age-matched elderly group. In line with previous studied here cited, we hypothesized that AMD subjects' reading performance will be poorer than control subjects and that visual-attentional training could improve their reading capabilities.

Materials and Methods

Participants

Twenty AMD subjects (mean age: 72.6 ± 0.9 years) and ten age-matched healthy control subjects (mean age: 69.3 ± 1.1 years) participated in this study, and were recruited from the Department of Ophthalmology in Quinze-Vingts Hospital (Paris, France) and from the Department of Ophthalmology in Hôtel-Dieu Hospital (Paris, France). Their participation was voluntary and free.

The exclusion criteria were the same that our previous study (see [25]) and all participants were native French speakers. Indeed, no participant was benefit of visual training before this study. In order to be comparable with a real life situation, the visual acuity was not an inclusion criterion. However, the calibration step was not validated for half of AMD participant probably because of their low visual acuity and/or the disturbed visual field (Figure 1). Moreover, in clinical routine, we observed that some AMD patients used (without learning session) a preferred retinal locus named PRL (to move their fixation in a healthy retinal area) to optimize their visual capabilities, and others AMD patients yet used the fovea. The first group validated the calibration step, and the second one did not validate it, consequently they were excluded by the study. The investigation adhered to the principles of the Declaration of Helsinki and was approved by our Institutional Human Experimentation Committee (ID-RCB: 2016-A01728- 23, CPP Ile-de-France: 16187). Written informed consent was obtained from each participant after the procedure was explained.

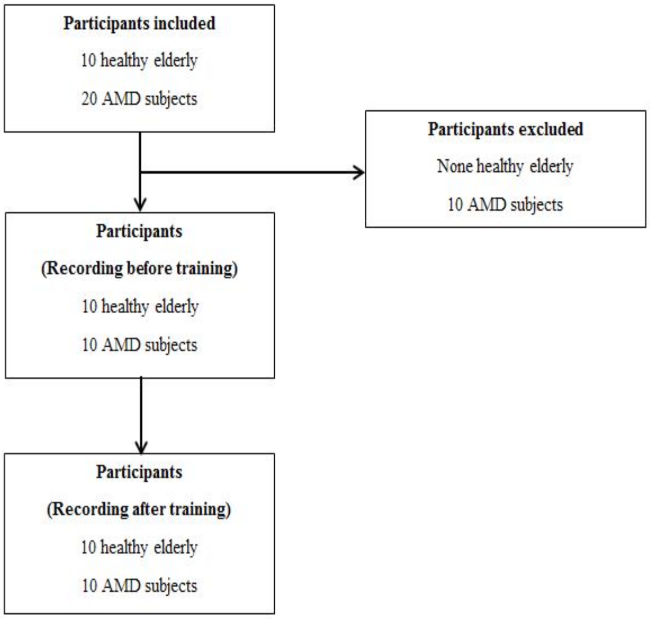
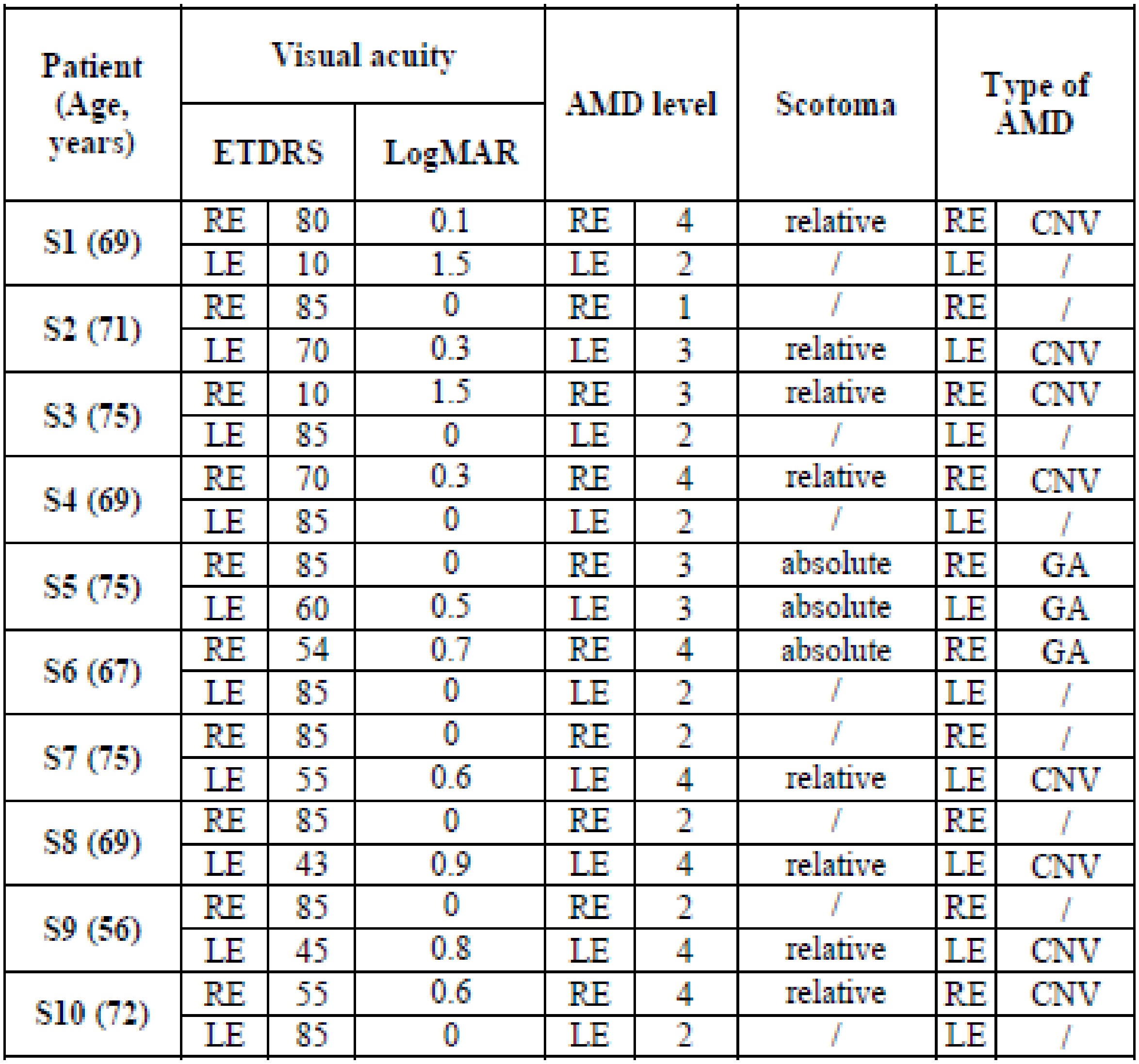


Figure 1: Flow-chart.

Ophthalmologic evaluation

All participants underwent ophthalmologic evaluation to evaluate their visual function. Clinical data of each AMD participants are shown in Table 1. We measured separately for each eye the visual acuity at far distance (5 m) with the Monoyer chart then translated to ETDRS and LogMAR with an adapted-scale. AMD subjects have a corrected monocular visual acuity between 10 (ETDRS) and 85 (ETDRS). All healthy elderly had normal visual acuity (≥85 (ETDRS)). We used the age-related macular degeneration severity scale of AREDS in order to identify the AMD level for each eye [26], using the SD-OCT (Spectralis®, Heidelberg Engineering). This imaging technique allowed observing the anatomic lesions (geographic atrophies or choroidal neovascularization). Among ten AMD subjects, we had eight subjects with choroidal neovascularization AMD and two subjects with atrophic AMD. Furthermore, we observed the presence or not of scotoma which can be absolute (no visual input) or relative (visual input disturbed).

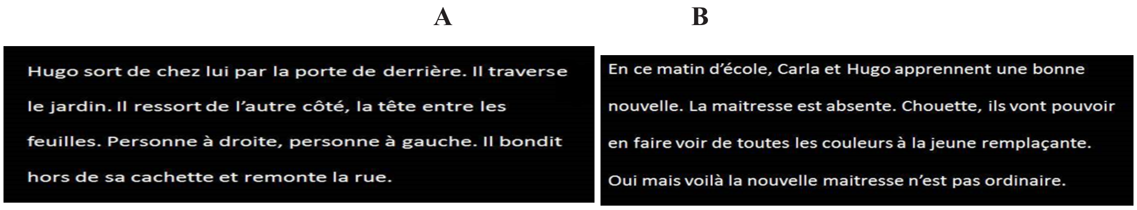


Patient (Age, years)	Visual acuity			AMD level		Scotoma	Type of AMD	
	ETDRS		LogMAR					
S1 (69)	RE	80	0.1	RE	4	relative	RE	CNV
	LE	10	1.5	LE	2	/	LE	/
S2 (71)	RE	85	0	RE	1	/	RE	/
	LE	70	0.3	LE	3	relative	LE	CNV
S3 (75)	RE	10	1.5	RE	3	relative	RE	CNV
	LE	85	0	LE	2	/	LE	/
S4 (69)	RE	70	0.3	RE	4	relative	RE	CNV
	LE	85	0	LE	2	/	LE	/
S5 (75)	RE	85	0	RE	3	absolute	RE	GA
	LE	60	0.5	LE	3	absolute	LE	GA
S6 (67)	RE	54	0.7	RE	4	absolute	RE	GA
	LE	85	0	LE	2	/	LE	/
S7 (75)	RE	85	0	RE	2	/	RE	/
	LE	55	0.6	LE	4	relative	LE	CNV
S8 (69)	RE	85	0	RE	2	/	RE	/
	LE	43	0.9	LE	4	relative	LE	CNV
S9 (56)	RE	85	0	RE	2	/	RE	/
	LE	45	0.8	LE	4	relative	LE	CNV
S10 (72)	RE	55	0.6	RE	4	relative	RE	CNV
	LE	85	0	LE	2	/	LE	/

Table 1: Clinical data of AMD subjects. Corrected visual acuity (ETDRS and LogMAR), AMD level, presence of scotoma (relative or absolute) and type of AMD (GA, geographic-atrophy; CNV, choroidal neovascularization) for each AMD subject.

Reading task

The reading task consisted of reading a four lines paragraph containing forty-one words (Figure 2). Because contrast sensitivity decreases with aging and AMD [27,28], we choose to use a text which was written in white "Arial" font on a black background. In order to test specifically reading processes, participants were asked to read the text silently and raise one finger when they finished. However, in order to verify the reading comprehension by participants, we asked two questions after the reading task. Reading recording was realized before and after training. Note that the text used in the two reading tasks (before and after training) was different but comparable in term of words frequency and number of words (see Figure 2A and B).



Hugo sort de chez lui par la porte de derrière. Il traverse le jardin. Il ressort de l'autre côté, la tête entre les feuilles. Personne à droite, personne à gauche. Il bondit hors de sa cachette et remonte la rue.

En ce matin d'école, Carla et Hugo apprennent une bonne nouvelle. La maitresse est absente. Chouette, ils vont pouvoir en faire voir de toutes les couleurs à la jeune remplaçante. Oui mais voilà la nouvelle maitresse n'est pas ordinaire.

Figure 2: Reading task used for participants (a/ before training; b/after training).

Eye Movements Recording

The Mobile Eye Tracker (Mobile EBT®, SuriCog), was used to record eye movements. It is a CE-marked medical eye tracking device which is composed of cameras allowing the capture of movements for each eye independently. The frequency of this system was of 300 Hz, and the precision of 0.25°.

Each participant was seated in a dark room, with the head stabilized by a headrest supporting both forehead and chin. Before to start the recording, a calibration was done: participant fixed a grid of 9 points (diameter 0.5 deg) mapping the screen. Each calibration point required a fixation of 250 ms to be validated. A polynomial function with five parameters was used to fit the calibration data and to determine the visual angles (see [29]).

Data Analysis

Calibration factors for each eye were determined from the eye positions during the calibration procedure (see [30]). The algorithm used to detect saccades is an adaption of what described by Nyström and Holmqvist (2010) [31]. MeyeAnalysis software (provided with the eye tracker) was used to extract the defining parameters of reading movements from the data for each participant before and after training. The duration of fixations, the number and the amplitude of progressive saccades (prosaccades, from left to right) and regressive saccades (backward saccades, from right to left) were analyzed. Two types of visual training were run: visually-guided saccades and visual attentional exercises lasting about 8-10 minutes depending of the subject.

Visually-guided saccadic paradigm

Visually-guided saccades were elicited on a PC screen of 22″ placed 60 cm in front of the participant. The central fixation target was a white filled circle subtending a visual angle of 0.5. After a variable fixation period ranged between 2000 and 3500 ms, the central target was disappeared and a target at the left or at the right side of the screen appeared for 1000 ms. The central fixation target then reappeared, signaling the beginning of the next trial. Each participant performed two blocks of different types of visually-guided saccades of different amplitude (5 deg, 10 deg, 15 deg and 20 deg); each block was separated by a few minutes of rest. Each block contained 30 trials randomly presented to the left and to the right side. Participant was invited to look at the target as accurately and as rapidly as possible. Examination looked the eyes position of participant throughout the test in order to verify the good realization of the test.

Visual-attentional training exercises

Metrisquare® software was used for visual-attentional training exercises (Figure 3). We used three exercises named "House", "Cat", and "Space rocket". The difficulty of visual- attentional task is different between each exercise: "house" exercise is composed by colored houses; some of these houses presented flame coming out from a window (Figure 3A). The instruction was to cross out as soon as possible all and only the houses without flames. The "Cat" exercise is composed by four different black drawings: a head of cats a flower, a sunshine and a tree (Figure 3B). Participant had to cross out as fast as possible all, and only the cat heads. The third exercise the "space rockets" there are black and white space rockets drawings (Figure 3C). Participant was invited to cross out as soon as possible the space rockets which are identical to the given model visible on top of the other space rockets during all the duration of the exercise. The three exercises were presented on a Wacom tablet and participant used a digital stylus allowing us to record his/her performance. Difficulty of test increases from the first one to the third.

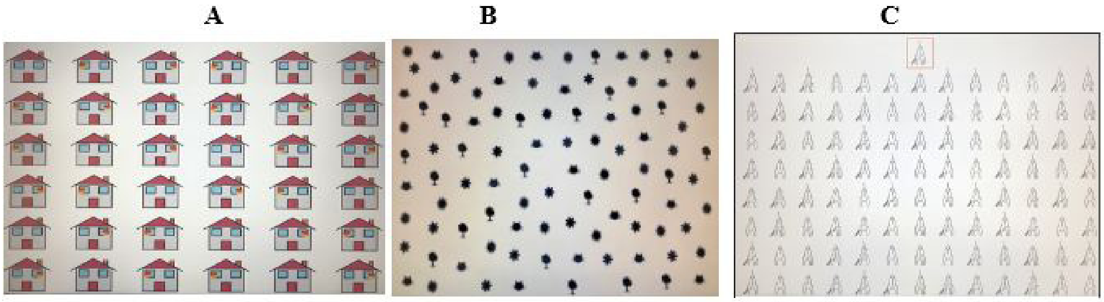


Figure 3: Visual-attentional exercises by Metrisquare® software: house (A), cats (B) and space rocket (C).

After these two training sections, participant made a short break of few minutes before the second reading recording, in order to reduce the impact of tiredness.

Statistical Analysis

Statistical analysis using the GLM (General Linear Models) in STATISTICA®. ANOVA was performed with the four groups of participants (AMD subjects and control age-matched subjects, respectively before and after training) as between-subject factors and the individual means of eye movements as within-subject factors. In the case of significant effects post-hoc Fisher's test (LSD) was performed. The effect of a factor was considered significant when the p-value was below 0.05.

Results

There was no significant age difference between the two groups ($F_{(1,18)}=3.53$, $p=0.76$).

Duration of fixations

Figure 4 shows the duration of fixation (ms) during reading for the two groups (control age-matched subjects and AMD subjects) tested before (BT) and after training (AT). The Analysis of Variance (ANOVA) indicated a significant group effect ($F_{(3.32)}=5.07$, $p<0.005$). Post-hoc comparison showed a significant difference between "Control (before training)" and "AMD subjects (before training)" ($p<0.0005$): without training, AMD subjects had longer duration of fixations than control subjects. Furthermore, post-hoc comparison did not show a significant difference between "Control (after training)" and "AMD subjects (after training)" ($p=0.50$): after training, AMD subjects normalized their duration of fixations during reading the text.

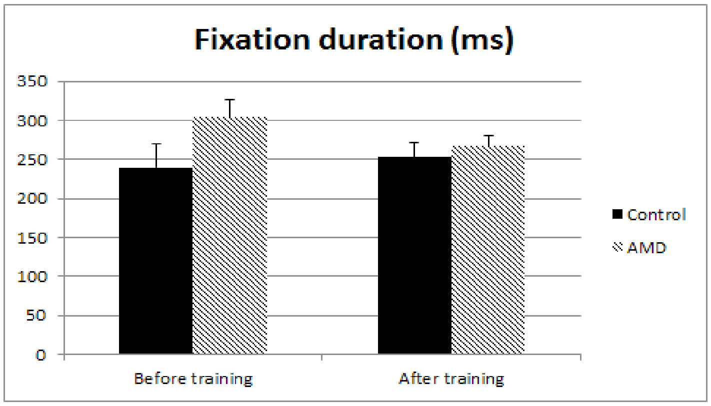


Figure 4: Mean of duration of fixations (ms) for each group of subject tested (control age- matched elderly before training, AMD before training, control age-matched elderly after training, and bilateral AMD after training). Vertical bars indicate the standard error.

Number and amplitude of pro- and backward saccades (Tables 2,3)

The Analysis of Variance (ANOVA) failed to show any significant group effect in the number of pro- and backward saccades ($F_{(3.32)}=0.12$, $p=0.9$ and $F_{(3.32)}=0.48$, $p=0.69$, respectively) neither in their amplitude ($F_{(3.32)}=0.21$, $p=0.88$ and $F_{(3.32)}=1.40$, $p=0.25$, respectively).

		AMD subjects	Controls	p value	Percentage differences (%)
Number	**BT**	25.90 ± 4.23	28.40 ± 2.31	0.92	9
	AT	27.87 ± 3.22	24.50 ± 1.40		13
Amplitude (°)	**BT**	4.81 ± 1.13	4.20 ± 0.26	0.88	14
	AT	4.17 ± 0.60	3.95 ± 0.56		5

Table 2: Mean and standard error of the number and amplitude (°) of prosaccades in AMD subjects and controls Before (BT) and After Training (AT), and percentage differences between the two groups.

		AMD subjects	Controls	p value	Percentage differences (%)
Number	**BT**	8.40 ± 2.01	10.40 ± 2.54	0.69	20
	AT	8.50 ± 1.72	6.50 ± 0.67		30
Amplitude (˚)	**BT**	4.22 ± 0.70	2.92 ± 0.40	0.25	44
	AT	3.05 ± 0.57	5.02 ± 0.70		40

Table 3: Mean and standard error of the number and amplitude (˚) of backward saccades in AMD subjects and controls Before (BT) and After Training (AT), and percentage differences between the two groups.

Time of reading task (Table 4)

The Analysis of Variance (ANOVA) did not indicate a significant group effect ($F_{(1.18)}$=0.77, p=0.38).

	AMD subjects	Control
BT	13.53 ± 2.07	8.2 ± 0.58
AT	12.53 ± 1.92	9.23 ± 0.78

Table 4: Time of reading task (s) in AMD subjects and controls Before (BT) and After Training (AT).

Discussion

The main findings of this study are as follows: (i) During reading a text, the fixation duration in AMD subjects was significantly longer compared to healthy elderly, while the number and the amplitude of prosaccades and backward saccades, and the time of reading task were similar between the two groups; (ii) AMD subjects only normalized their duration of fixations after training. Each of these findings will be discussed below.

Oculomotor pattern in AMD subjects during reading

This study showed that during reading a text, AMD subjects had longer duration fixations than healthy elderly; in contrast, the number and the amplitude of prosaccades and backward saccades were similar between two groups. This is on line with studies cited in Introduction section [15,16].

Recall that during reading, subject had to make saccades to bring their eyes on the words, and fixations to identify, memorize and understand the word. When visual input is disturbed, reading is defective. As reported for strabismic subjects [30,32], duration of fixations is abnormally longer in these subjects with respect to normal subjects probably due to the incorrect visual inputs coming from the deviated eye. Then, the increase of fixation duration in AMD subjects could be due to the wrong visual inputs from the sick eye leading to more time needed to fixate and focus the word to be read.

Interestingly, in the literature there are few studies exploring reading performance in subjects with glaucoma (a visual pathology which affects the peripheral visual field in elderly). For instance, Murata, et al. (2017) compared, with an eye-tracker, silent reading performance of Japanese text written horizontally in 50 glaucoma subjects (mean age: 52.2 years) and 20 age-matched controls, and they showed an increase of fixation duration in glaucoma subjects compared to controls, and a correlation between the increase of fixation duration and the visual field deficit of these patients [33]. Rolle, et al. (2019) also compared the loudly reading performances of Italian text in 80 glaucoma subjects (mean age: 62.5 years) and 60 healthy age-matched controls, without objective eye movements recording [34]. They showed a correlation between the severity of visual field deficit and the slow reading speed, and several mistakes during reading in glaucoma subjects. The authors suggested that glaucoma, like other visual pathologies, could reduce perceptual span requiring more attention to fixate the target. Then, the longer duration fixation found in AMD subjects in our study could be due to abnormal visual input: low visual acuity as well as central visual field deficit. Secondly, in our study, we reported that there was no significant difference in the number and amplitude of prosaccades and backward saccades between AMD subjects and healthy elderly subjects. This finding would be explained by the fact that both AMD and elderly subjects had acquired during their childhood correctly reading capabilities, consequently their ability to bring the two eyes on the text to read remains intact.

AMD subjects normalized the fixation duration after training

Our results showed, for the first time, an improvement of fixation duration after a short period (8-10 minutes) of oculomotor and visual-attentional training in AMD subjects. This finding enlarges the previous studies exploring the benefit of oculomotor training type in reading capabilities in AMD subjects using a long training period (see in Introduction section [21,22]). We suggest that the combination of two types of training (oculomotor and visual- attentional) improves the benefit of training. There are some techniques to train successfully the reading performances in AMD subjects [35]). In a retrospective analysis, Palmer, et al. (2010) studied the impact of training (one weekly session of one hour) on reading performances in 300 AMD subjects [36]. The goal of this training was to learn to use the preferred retinal locus and magnifier low-vision aids. The benefit was evaluated by reading performances (reading speed, font size, duration of comfortable reading and comprehension). The results showed an improvement of reading performance, that the mean number of sessions required was 3.8, and that there was no evidence that more five sessions improved performances. The authors made the hypothesis that attentional process decreased with aging, consequently it would not be necessary to make a long training period in elderly. We thought that short training sessions daily would be more efficient than longer sessions weekly. This hypothesis, however, need to be further explored. According to Rizzolatti, et al. (1987), attention is strictly linked with saccades, consequently our training type activated cortical areas responsible in triggering both attention and saccades leading to develop compensatory mechanisms in order to change in oculomotor pattern during reading in AMD subjects [37]. Such adaptive mechanisms could develop rapidly, after 10 minutes of training.

Please note that the impact of oculomotor and visual-attentional training was examined directly after the training session. In the future, it could be interesting to evaluate maintain of this impact in long time (few days or weeks after the training).

Finally, we must notice that we did not observe any modification in oculomotor pattern during reading in healthy elderly after visual-attentional training. We hypothesized that a longer training duration (several training sessions) will need to affect oculomotor performance during reading in healthy elderly. This hypothesis needs to be tested further. In the future, it could be interesting to do a follow up study to explore the benefit of training in time. Most studies trained reading performances by using a reading training type; we suggest that a visual-attentional training could be is a better strategy and could be easily develop by specialist of vision for helping AMD subjects.

Conclusion

The present study shows that in AMD subjects the duration fixation during a reading task is significantly longer with respect to healthy elderly, but it normalizes after visual- attentional training type. Additional studies will be necessary to explore further the effect over time of visual attentional training in these subjects.

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