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# Balance training and visual rehabilitation of age-related macular degeneration patients

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**Abstract**. Patients with Age-Related Macular Degeneration (AMD) experience a large scotoma precluding central vision. In addition, 2/3 of these patients present visuomotor and balance deficits resulting in clumsiness and increased risk of falls. On the basis of previous work demonstrating that visual, vestibular and somatosensory functions involved in balance control can be rehabilitated by training, we attempted to improve these functions by balance training. We measured the impact of balance training on several visuomotor functions and reading speed.

We compared balance status of 54 AMD patients to 55 normal controls. Sixteen of these patients and 14 controls subsequently received balance training sessions on a postural platform (Multitest®) stressing sensorimotor coordination by selectively inhibiting or disturbing either, visual, vestibular or somatosensory input. Producing a conflict between two inputs reinforces the use of the third.

We assessed postural sway, pointing accuracy, reading performance and, for the patients, the effect of low vision training and balance training on the shift from several spontaneous Preferred Retinal Loci (PRLs) to one or more Trained Retinal Loci (TRL). Even after a limited number of sessions of cross-modal balance training, the results show a significant improvement for the vestibular input and fixation stability. A decrease of visual dependency was observed only in the control group. Apart from these improvements, pointing accuracy and reading speed were not significantly improved compared to controls, leading to the conclusion that more training sessions may be necessary to gain more significant improvement of visuo-motor functions.

Keywords: AMD, postural sway, aging, rehabilitation, gaze control, reading

## 1. Introduction

It is known that efficiency of sensory and motor functions decrease with aging [6]. This results in increased risk of falls [28] and, as far as visual functions are concerned, mishaps in everyday tasks involving changing light levels, stereopsis, glare, and low contrast [4]. These impairments are further increased in the case of Age-Related Macular Degeneration (AMD). This pathology presents two modes of occurrence: a progressive dry form (80% of the cases) which is insensitive to treatment and a more rapid neovascular form (20%) which is responsible for more than half the cases of blindness caused by this disease [1]. Both types result in vision loss to the central 15–20 deg of visual field (i.e. central scotoma), thus preventing localization of targets and recognition of faces or other objects, although peripheral vision is relatively spared. Even if in some cases the scotoma is not absolute, the patient ultimately loses reading capacities and becomes less stable. Central fixation, dependent on foveal function is lost and consequently prevents the patient from directing his/her gaze intentionally, increasing the attentional

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load and disturbing localization in the environment.

In addition to visual loss, normal aging of sensory inputs is characterized by a reduced vestibular excitability [2], a reduced sensitivity to contrast and motion [27] and somatosensory sensitivity [35]. As a consequence, two-thirds of the patients with AMD present balance deficits [11].

Balance control involves somatosensory, motor, visual and vestibular systems each with a differential sensory weighting as a consequence of functional automatisms activated during postural regulation [23,31]. Balance is dependent upon visuo-spatial coordination which requires interactions between visual localization by the retina and the proprioceptive inputs from the extraocular muscles, other proprioceptive and vestibular inputs and motor commands [19].

Once deprived of central vision, AMD patients attempt to acquire visual information located straight ahead through the utilization of areas of peripheral retina called Preferred Retinal Loci (PRL) [10]. However, the patient has no cue to know which PRL detected the perceived object. As a consequence, he/she does not control the localization of the object and any attempt to look again or catch it is largely inefficient and disturbing. However, some patients will tackle this difficulty by developing spontaneously an appropriate control of their fixation.

Rehabilitative procedures have been proposed to alleviate the deficit by fostering the use of one or a restricted number of optimal eccentric retinal loci [15, 29], hence called Trained Retinal Locus(i) or (TRL). The result of Goldmann visual field perimetry provides cues for the choice of the PRL to be trained. In most cases, the scotoma extends around the macular region, approaching the optic disk. It appears that some PRL, located in between the scotoma and the optic disc, are not fit for reading, as they do not provide a large enough region for the projection of a complete enlarged word.

When the medical condition of the eye is stabilized, it usually takes about three months for the patient to accept his/her condition and be prepared to accept the load of a rehabilitation program. During this 3 months delay, the patient may have mentally accepted the deficit and developed one or more PRL [8] and partially rereferenced his/her oculomotor system [38]. Some patients spontaneously developed an efficient gaze control and functional capacities with optical aids. Most of them require a rehabilitation program which is proposed after an initial assessment.

The rehabilitation procedure is based on low vision training techniques in order to help the patients in mastering the use of eccentric gaze. Goldmann perimetry data informs the choice of a prospective Trained Retinal Locus (TRL). During rehabilitation, the trainer helps the patient to reinforce the use of one or a limited number of Trained Retinal Loci for visual tasks, including reading [12,17,33]. Ultimately, optical aids are provided to the patient in addition to the best optical correction to improve daily life performance [16]. Optical filters, magnifiers, closed circuit television enlargers and telescopes are the most common optical aids available.

In this study, we investigated to what extent specific stimulation of each component of body stability would result in a global improvement of postural control, including voluntary control of eye position [36]. We choose balance training, involving somatosensory, visual and vestibular inputs, to evaluate if it would be efficient to improve stability of the center of gravity, manual pointing accuracy and stabilization of one or more TRLs.

The first hypothesis is based on the observation that physical activities contribute to the stabilization of posture and gaze [14]. We hypothesized that specific training of the sensorimotor functions involved in static and dynamic balance control would foster the control of eye fixation as demonstrated by the use of a single, or a limited number of TRLs.

A second hypothesis is that this improvement of balance control would not only improve eye fixation but also accuracy of hand pointing and reading speed. Thus, for this study, following a balance assessment for all the participants, a subgroup of the patients and normal controls was trained on a static and dynamic balance platform in order to stimulate concurrently the visual, vestibular, somatosensory and oculomotor functions. Ultimately, we hypothesized that balance training could accelerate recovery of reading capacities.

## 2. Methods

### *2.1. Participants*

The study was approved by the ethical committee "Comité Consultatif de Protection des Personnes dans la Recherche Biomédicale" (CCPPRB) – Lyon B – and adhered to the tenets of the Declaration of Helsinki. We conducted a prospective study among a series of consecutive patients. Patients were recruited in a private ophthalmology clinic. Controls were either accompanying persons or volunteers recruited by word of

Table 1
Participants

| | Number of cases | Age | Tests |
|---|---|---|---|
| Group 1 | 54 AMD patients | 77.91 (63–87) | Balance assessment |
| Group 2 | 16 AMD (from Gp 1) | 75.81 (68–82) | Balance assessment<br>Balance training |
| Group 3 | 55 normal controls | 70.54 (60–85) | Balance assessment |
| Group 4 | 14 normal (from Gp 3) | 70.64 (60–80) | Balance assessment<br>Balance training |

mouth. All participants gave informed written consent for participation to the study.

We tested 4 groups of participants (Table 1).

Group 1: Fifty-four AMD patients constituted a database.

Group 2: Sixteen individuals from Group1 were selected according to their availability to comply with the experimental procedure to perform a balance-training program in addition to their low vision rehabilitation. As such, they may not be strictly representative of Group1.

Group 3: Fifty-five normal controls.

Group 4: Fourteen individuals from Group 3 were selected according to their availability to comply with the experimental procedure to perform a balance-training program.

Inclusion criteria for Group 1 (AMD patients): Age range between 60 and 87 years. Best eye corrected visual acuity (VA) $<$ than 0.4 log MAR (decimal 0.4).

Inclusion criteria for Group 3 (Controls): Age range between 60 and 85 years. Corrected binocular VA $\geqslant$ 0.2 logMAR (decimal 0.63).

Exclusion criteria for all Groups: Neurological disorders proven during last 10 years, i.e. agnosias, balance disorder, vestibular pathologies, history of cranial trauma, cerebral or tumoral pathologies, prostheses of hips and knees, diabetic presenting with somatosensory disorders of the limbs, peripheral scotoma, hemineglect, significant anisometropy, diplopia, nystagmus, debilitating presbycusis.

The range of patients' VA was 1.4–0.5 logMAR (0.04–0.32 decimal) (standard Early Treatment Diabetic Retinopathy Study (ETDRS) scale) (Table 2). The central scotoma was determined by Goldmann kinetic visual field perimetry. Image recognition, visually guided hand movements (pointing, tracing, crossing, circling) and reading capacities were evaluated. All participants had ENT assessment showing no pathology except regular presbycusis.

Compliance. One patient from Group 2 and one control participant from Group 4 did not complete the protocol. All other patients complied with the rehabilitation sessions and did the homework provided in between sessions, sometimes more than requested.

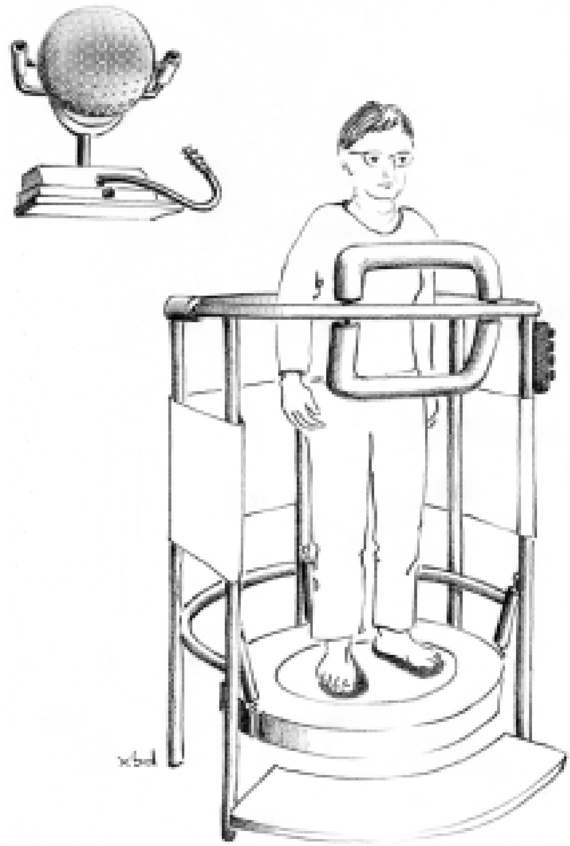

Fig. 1. Multitest Framiral® platform and optokinetic stimulator (enlarged).

### 2.2. Equipment

#### 2.2.1. Balance platform

We used a platform designed for standing (static) and dynamic balance assessment and rehabilitation (Multitest Framiral®, http://www.framiral.fr/fr/multitest.php), (Fig. 1).

The assessment program included a stability index, area of center of gravity projection and mean velocity of center of gravity displacement. These data indicated the respective contributions of somatosensory, visual, and vestibular inputs regulating balance control, as

Table 2
Patient's data. Acuity is given in LogMAR and (decimal). The VA of participant 12 could not be estimated. Type: atrophic (a) or neovascular (n). Scotoma: relative (r) or absolute (a). Two reading tests were used, INI and AMDREAD

| Sex | Patient N° | Age | Visual Acuity LogMAR | Type | Scotoma | Text | |
|---|---|---|---|---|---|---|---|
| F | 1 | 68 | 0.6 (0.25) | n | r | INI | |
| F | 2 | 72 | 0.5 (0.32) | n | a | AMDREAD | |
| F | 3 | 72 | 0.5 (0.32) | a | a | AMDREAD | |
| F | 4 | 73 | 1.4 (0.04) | a | a | INI | |
| F | 5 | 74 | 1.1 (0.08) | a | r | INI | |
| F | 6 | 74 | 1 (0.1) | a | a | AMDREAD | |
| F | 7 | 75 | 1.1 (0.08) | n | r | INI | |
| F | 8 | 77 | 1 (0.1) | a | a | INI | |
| F | 9 | 77 | 1.2 (0.0625) | an | r | INI | |
| F | 10 | 77 | 0.7 (0.2) | a | r | AMDREAD | drop out |
| F | 11 | 78 | 0.8 (0.16) | n | r | INI | |
| M | 12 | 77 | missiNg | a | a | AMDREAD | |
| M | 13 | 77 | 0.7 (0.2) | n | r | AMDREAD | |
| M | 14 | 79 | 0.7 0.2) | a | | AMDREAD | |
| F | 15 | 81 | 1 (0.1) | n | | INI | |
| F | 16 | 82 | 1 (0.1) | an | r | AMDREAD | |

well as visual dependence. These figures were calculated by a built-in program based upon the following parameters:

Somatosensory = Surface A/Surface B $k1$ (*)
Vision = Surface A/Surface D $k2$ (*)
Vestibular input = Surface A/Surface E $k3$ (*)
Visual dependence (1) = [(Surface C + F)/(Surface B + E) $k4$] – 1 (*)
*k1, k2, k3, k4* = coefficients defined by the manufacturer
(*) Except in the event of falls

where Surface A is the extent of the displacement of the center of gravity in a normal subject standing on the platform in stable condition, eyes fixating a target. Surface B, stable platform, eyes closed. Surface C, stable platform, eyes open, optokinetic stimulation, no fixation target. Surface D, servo-controlled platform, eyes open fixating a target. Surface E, servo-controlled platform, eyes closed. Surface F, servo-controlled platform, eyes open and optokinetic stimulation. Normative data are available for this equipment [22].

The platform was surrounded by a high fabric screen hanging from ceiling to floor at a distance of 2 m from the participant. A fixation spot and other visual targets could be projected on the screen at the level of the participant's eyes. Adjacent to the platform a multidirectional optokinetic stimulus projector displayed a constellation of dots (mean diameter 2 degrees) on the whole surface of the screen, moving in a chosen direction at a velocity ranging from 15 to 20 deg/sec.

The platform and visual stimulations were controlled through the Multitest program set in a PC computer that collected and computed the results of each test.

The patient was placed in virtual darkness after an adaptation period of 10 mn in dim light. The computer control screen at its lowest level and located outside the screen was the only source of light.

### 2.2.2. *Goldmann visual field perimetry*

Dynamic Goldmann visual field perimetry measures the extent and depth of the scotoma as well as the level of sensitivity of the spared retinal areas at different levels of target contrast. The stimulus could be varied by precise increments of brightness and size, and could be easily presented to any location of the retina. Brightness of the test spot at full illumination was 1000 asb. The test required prolonged and sustained attention from the patient and a skilled experimenter (Fig. 2).

Three isopters were determined to obtain a picture of the overall extent of the visual field and thus give a measure of the sensitivity of the areas of the visual field.

### 2.2.3. *Pointing test*

A pointing test was presented on a 21inch CRT touch screen at a distance of approximately 28.5 cm from the participant's eyes. The instructor positioned and maintained the patients' heads at the appropriate distance, as they tended to bend backward. A total of 20 targets (cross-shaped, 2 deg or 1 cm wide) were displayed randomly in the middle or in one of the four corners of a rectangle (40 $\times$ 30 deg or 20 $\times$ 15 cm). Peripheral targets were 24° or 12 cm distant from the center. The participant was instructed to perform the best

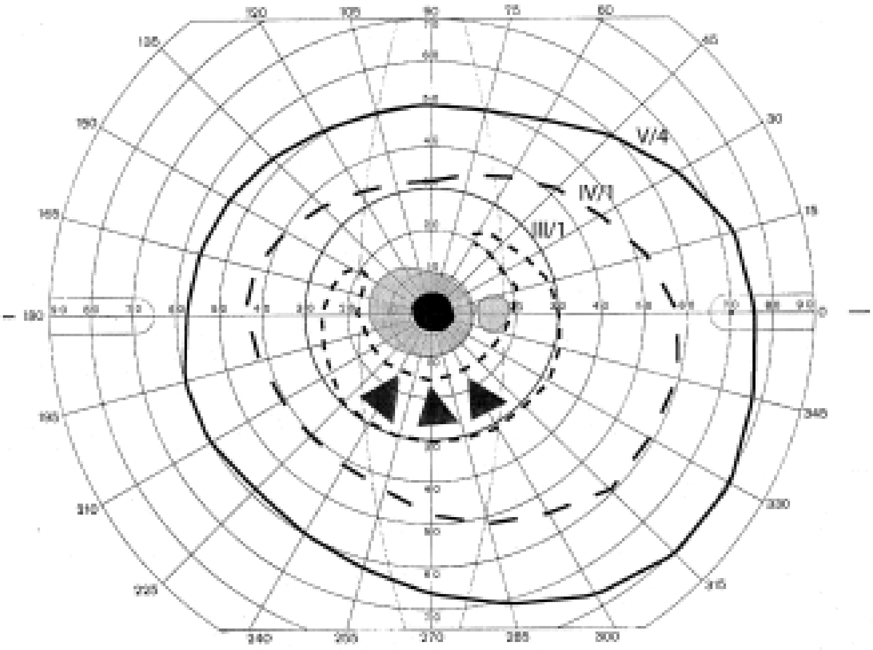


Fig. 2. Goldmann perimetry data sheet. V/4 (target size of 16 mm 2, full illumination), IV/1 (target size 16 mm 2, relative illumination 0.0315) and III/1 (target size 4 mm 2, relative illumination 0.0315). Velocity was about 4 deg/sec as recommended by Johnson and Keltner [24]. Arrows represent locations for appropriate TRL.

accuracy-velocity compromise. Distance and pointing errors were recorded.

*2.2.4. Reading test*

The patients wore their glass optical correction and, if needed, multifocals or a telescopic optical system. Similar sized texts were used following a standard protocol, whatever the visual acuity of the subject. However, the subject was allowed to adjust the reading distance. Two equivalent series of reading texts were used over the duration of the experimental procedure, one from the Institution Nationale des Invalides [37], the other from AMDREAD [18]. Some patients were tested on both tests to ascertain that they gave similar data. For measuring the reading speed, the text was placed on a recline stand with adjustable slope under a swiveling fluorescent cold light (Fig. 3). The patient could bring the text as close to the eyes as needed. Reading speed was recorded in words per minute.

Fig. 3. Reading test on an oblique stand. This patient used a telescopic optical system.

### 2.3. Procedures

The rehabilitation program was initiated about 3 months after stabilization of the retinal pathology, thus helping to ensure that patients reach an acceptance point on the disability adjustment scale. The low vision rehabilitation began with an initial assessment consisting of a variety of tests including VA (ETDRS), form perception, reading speed, visuo-motor coordination and dynamic Goldmann visual field perimetry

Follow up rehabilitation sessions consisted of training the patient to gain control of one eccentric location, to recognize single letters, then groups of letters, to control hand position when pointing, drawing, circling, crossing or barring targets. Additional pencil and paper exercises of the same sort were provided to be done at home for practice. The participants brought them back on the following visit for evaluation. All participants complied with this task and often spontaneously did more home work than required. Final and follow-up assessments were performed to allow comparison with the initial assessment and evaluate the benefits of the procedure.

*2.3.1. Determination of fixation points*

The locations of the PRLs spontaneously used by the patient are determined by examining the position of the Hirschberg corneal reflex relative to the pupil. From the position of the reflex of a fixation lamp placed in front of the patient, the examiner determines which eye is fixating. The distance and direction of the reflex from the center of the pupil indicate roughly the location of the fixating point on the retina.

*2.3.2. Initial balance assessment*

All participants underwent an initial assessment performed successively in stable and servo-controlled conditions on a balance platform (Multitest Framiral®). The participant was placed bare-feet inside marks indicated on the platform, arms hanging along the body. The room was dark. Instructions were given to keep silent, not to move the feet, to keep balance and hold upright, and to avoid touching the protective barrier. Any contact with the barrier was recorded as a "fall". Three pressure sensors recorded the position of the center of gravity of the participant at a frequency of 50Hz.

In the servo-controlled condition, the platform moved freely under the pressure of the feet so that the patient had to permanently counterbalance the instability of its center of gravity.

The sensory assessment included stable and unstable conditions. In each condition, 3 sequences of 30 seconds were performed: fixating a red spot, eye closed and watching optokinetic stimulation. This duration was estimated long enough to obtain reliable data without overloading the patients. For this initial assessment, the top to bottom direction of optokinetic stimulation was chosen arbitrarily and applied to all participants. Recording began after a countdown of 5 seconds. The end of the sequence was announced by a jingle.

The sets of 30 sec sequences were blocked as follows:

1st: stable platform, eyes open fixating a red dot directly in front

2nd: stable platform, eyes closed

3rd: stable platform, eyes open, optokinetic stimulation

4th: unstable platform, eyes open fixating a red dot directly in front

5th: unstable platform, eyes closed

6th: unstable platform, eyes open, optokinetic stimulation.

In the interval between sequences 3 and 4, the platform was brought to its unstable condition with the participant holding the safety barrier. He/she was then invited to release his/her hands from the barrier and experience the new situation for 45 sec before recording was started.

*2.3.3. Balance training*

The participants agreed to come to 5 training sessions. This limited number was chosen to optimize compliance. A regular program for prevention of fall would normally include more sessions, but was not applicable in an ophthalmology clinic. The purpose of 5 similar training sessions was to stimulate each sensory input by various exercises in stable and servo-controlled unstable platform conditions. In each situation one input is predominant although not exclusively involved. Training sessions (25 min) were performed once a week for 5 consecutive weeks. This length for each session is common in fall prevention programs.

Somatosensory:

To emphasize the contribution of the somatosensory system, the participant fixated a red dot at eye level while the platform is kept stable. Then he/she closed eyes during 15 sec, re-opened for 10 sec, and closed again for 30 sec, re-opened for 10 sec, and closed again for a total of 30 sec.

Visual:

Two situations emphasized the contribution of visual system feedback. On the stable and dynamic servo-controlled condition, the participant was submitted to an optokinetic stimulation varying in velocity and direction (from 15 to 20 deg/sec, and from vertical motion to all directions) with the progression of the sessions. In the following situation, the center of gravity was projected, every 500 ms (2 Hz), as a square on the screen in front of the participant and its path remained on the screen. The participant was instructed to move the projection of the center of gravity along a definite discontinuous path by controlling the position of the platform. There were 3 different paths, columnar, circular and heart shaped, composed of spots of varying sizes. This exercise was first made in stable and then in servo-controlled dynamic condition.

Vestibular:

On the stable platform, the participant had open eyes and maintained eye fixation on a red dot directly in front of him/her, while moving the head back and forth right to left and up and down during 30 sec each. In the dynamic servo-controlled condition, the participant was fixating the red dot for 2 min followed by 2 min with eyes closed. Meanwhile, semi-random jerks destabilized the platform, under the control of the experimenter. This situation emphasized the contribution of the vestibular system. The 3 conditions mentioned above were randomly counterbalanced from session to session. The training sessions were made increasingly difficult, by enlarging the range of servo-controlled platform motion and adding more jerks of larger amplitude and by increasingly discontinuous paths stressing visuo-motor control.

#### 2.3.4. *Final balance assessment*

The participants from Groups 2 and 4 who were trained on the balance platform had a final and follow up (15 days) assessment, identical to the initial assessment. The results were compared to those of Groups 1 and 3 who had no balance training.

#### 2.3.5. *Pointing task*

The pointing task was performed in a dimly lit room. The participant was seated facing the CRT screen, which constituted the only source of light. The dominant hand was used, starting from resting on the table. Instructions were given to point to the target as accurately and quickly as possible and to bring back the hand to the starting location on the table. A beep preceded the display of the target at a random time interval.

#### 2.3.6. *TRL stabilization assessment*

PRL and TRL number and localizations were estimated by the Hirschberg technique of corneal reflex [5].

#### 2.3.7. *Reading test*

We used standardized texts of about 130 words. The participant was instructed to read aloud as fast as possible, without making comments. The reading speed was recorded as well as pauses, repetitions, omitted words, and word errors. Comprehension of the content was assessed. Reading speed alone is considered here.

### 2.4. *Statistical analysis*

All statistical analyses were performed using the software Graphpad Prism 4. Because the sample sizes were small, changes in performance were tested using the non-parametric Student t and Mann-Whitney tests. A test of proportions was used to analyze the significance of the number of falls in Control and Patient groups before and after training on the platform.

## 3. Results

### 3.1. *Initial balance assessment*

Balance data provided by the program built-in the platform gave an estimate of Somatosensory (SOM), Vestibular (VEST), Visual (VIS) inputs and Visual Dependence (DEP) (Table 3). An optimal response from normal participants would be close to 100 for somatosensory, vestibular and visual inputs and close to 0 for visual dependence, meaning that the displacement of the center of gravity in each condition is minimal and the participant does not depend on visual cues to keep control of its sway.

AMD patients rely significantly more than controls on their somatosensory input. In both groups 1 (AMD patients) and 3 (controls), somatosensory scores were higher than vestibular. Unexpectedly, AMD patients showed a rather low vestibular input and their fairly high visual dependence was not significantly different from that of controls.

The number of "falls" was defined as a hand contact with the safety barrier. The initial balance assessment revealed twice as many falls for AMD patients than for controls. Globally, Patients and Controls did differ significantly on somatosensory and vestibular parameters.

### 3.2. *Balance training*

The expected goal of balance training was an improvement of the use of each sensory input (nearer to 100%) and a decrease of visual dependency (nearer to 0%).

Control participants fit this expectation (Table 4). A significant improvement of Somatosensory input and diminution of visual Dependency was observed at the follow-up but not at the final assessment (Mann-Whitney test, $p < 0.05$). An apparent but no significant improvement of the vestibular input was observed.

Table 3
Balance assessment data for all participants: Mean 95% CI

| | Initial test | | Student t test |
|---|---|---|---|
| | Patients $N = 54$ | Controls $N = 55$ | |
| SOM | $90.94 \pm 5.18$ | $82.41 \pm 6.48$ | S |
| VEST | $62.3 \pm 12.02$ | $78.87 \pm 8.54$ | S |
| VIS | $57.38 \pm 10.45$ | $63.8 \pm 10.31$ | NS |
| DEP | $30.21 \pm 10.04$ | $27.57 \pm 9.97$ | NS |
| Participants with falls | 24 (44.44%) | 12 (21.81%) | |

S: statistically significant ($p < 0.05$), NS: statistically non significant.

Table 4
Balance data for patients and control participants before and after balance training: Mean $\pm$ 95% CI

| | Initial test | | After platform training | | 15d follow up | |
|---|---|---|---|---|---|---|
| | Patients $N = 15$ | Controls $N = 13$ | Patients | Controls | Patients | Controls |
| SOM | $86.27 \pm 10.27$ | $82.08 \pm 12.91$ | $86.20 \pm 13.37$ | $88.62 \pm 11.23$ | $93.60 \pm 9.71$ | $99.00 \pm 2.00$* |
| VEST | $67.73 \pm 19.92$ | $77.38 \pm 23.68$ | $95.40 \pm 7.01$* | $91.85 \pm 13.63$ | $87.00 \pm 13.87$ | $97.64 \pm 4.74$ |
| VIS | $61.20 \pm 15.23$ | $61.54 \pm 25.91$ | $76.93 \pm 13.74$ | $78.85 \pm 19.68$ | $64.00 \pm 19.43$ | $78.18 \pm 16.07$ |
| DEP | $18.60 \pm 15.02$ | $36.08 \pm 24.40$ | $12.87 \pm 12.74$ | $13.00 \pm 9.16$ | $25.47 \pm 18.55$ | $9.00 \pm 13.10$* |
| Participants with falls | 5 (33.33%) | 5 (38.46%) | 2 (13.33%) | 0* | 2 (13.33%) | 0 |

*: statistically significant, Mann-Whitney test, $p < 0.05$.

A preliminary inspection of the data did not suggest a blatant deviation from normality.

The patients showed a significant improvement of the vestibular input only, which was not maintained over time but remained fairly good.

Finally, the number of "falls" was significantly reduced in the control group only and maintained after 15 days. In the patient group, however limited in number, an apparent reduction was not significant, and this trend was maintained after 15 days.

### *3.3. Pointing*

Comparison of pointing accuracy before platform training, after platform training and at the end of the low vision rehabilitation program showed a non-significant tendency toward improvement in pointing accuracy in the control group (Table 5).

It could hardly be attributed to procedural training because the two sessions were performed at a minimum of 6 weeks interval. It was noticeable that AMD patients did not improve their performance significantly on this test.

### *3.4. TRL stabilization*

It was expected that the patients would develop the use of a single or limited number of TRL through which they could acquire stable spatial references. The choice of the TRL to be trained was determined from the result of Goldmann dynamic perimetry. Some patients (Group 2) were offered a series of balance training on the platform on grounds that they had difficulties to develop the use a single TRL after a few sessions of low vision rehabilitation. A significant reduction in the number of PRLs was observed as compared to initial assessment data and to control group data.

Before platform training, one patient used one PRL, 2 used 3 and the other patients used multiple PRLs as deduced from the corneal reflex. After platform training, 4 patients used only 1 TRL, 4 used only two, and 5 used 3 TRLs (Table 6). In 9 patients out of 13, the TRL that stabilized after platform training matched the location expected from the data of the visual field perimetry. In each case a single TRL was used for efficient reading.

The results showed that 9 patients developed the use of the expected TRL, 4 of them using a single TRL. Two patients used a TRL 30° from the expected location, 3 used inefficient TRLs that will require further rehabilitation sessions to shift to an optimal TRL location.

### *3.5. Reading performance*

Reading speed was coded in words per minute (Table 7). An apparent reading speed improvement in both groups of patients after low vision rehabilitation was not significant. The beneficial effect of platform training to the vestibular input did not transfer to improve reading speed, although the confidence intervals are large, the trend is in the right direction. More training sessions might reveal a significant effect.

## 4. Discussion

On the one hand, our study confirms that the vestibular, somatosensory and visual scores obtained by AMD patients as well as age-matched controls, were never optimal, demonstrating a global age related degradation of these three inputs, as described earlier [20]. The low score for vestibular is coherent with the number of falls, more frequent within the patient group as compared to the control group. However, the patients showed a better somatosensory input score than the control group, a result that could be interpreted in light of a compensatory effect for the low vestibular input [13].

Somatosensory and visual dependence did not improve significantly by training in all groups of participants. For the control group, the somatosensory input was increased by 6.54% between the initial test and the end of the training, and by 16.92% two weeks later. This last improvement could be a consequence of the spontaneous practice by the participants who have acquired better control of their muscular performance although the number of balance sessions was limited to five. In clinical practice, the number of sessions of a typical posture, balance and mobility program is close to 2 weekly sessions during 3 months [21]. Other studies have shown that physical exercise improves stabilization of posture [7,14,29,32].

For the patients group, vestibular input increased by 27.67% after balance training, but this was not maintained over time and a decrease of 9.33% was observed after 15 days. This suggests that they might need more balance training sessions and that lessons learned may not be retained. In any case, even considering this loss, the remaining benefit (18.34%) was close to what was observed with the control group. We noticed an equally considerable reduction of falls in all the participants, normal and patients. This was particularly beneficial to the patients as a previous study described vestibular pitfalls in macular degeneration patients [34].

In the pointing task, a hypometric trend was observed to the peripheral targets and a systematic error to the central target. Both showed a slight non-significant improvement after balance training. It would be interesting to investigate if more training of ocular saccades and pursuit on the platform would help with the pointing accuracy.

TRL stabilization was significantly improved after balance training. The location usually matched the expected location on the retina in straight ahead fixation that was determined from the result of the initial Goldmann perimetry. Although not very accurate, the Hirschberg reflex revealed the direction of the fixation point and gave an estimate of its eccentricity [5]. It was an easy, non-invasive way for an experienced experimenter to monitor the retinal sector used by the patient all along the training sessions and so to assess the progress during rehabilitation.

An alternative method to determine which retinal area should be trained has been introduced by Mackeben and Colenbrander [30]. The patient has to look at the center of a wagon-wheel pattern and identify letters flashed on different sectors of the screen. The Macular Mapping Test is very short and easier to apply but does not map the depth and the precise limits of the scotoma, so we did not use it.

The optimal way to assess the location of fixation on the retina is the use of a Scanning Laser Ophthalmoscope, a technique that was not available.

We observed an initial number of PRLs significantly higher than usually reported in the literature [9]. Although we had no direct explanation for this discrepancy, we could propose several suggestions. First, some of the patients were selected for balance training because they experienced difficulties choosing a single eccentric fixation point. They were offered balance training with the hypothesis that this would boost their sensorimotor control as a whole. A second suggestion concerns the relative inaccuracy of the Hirschberg technique. Third, our patients were older (mean age 77.91 years-old, range 63–87) than the patient group of Lei and Schuchard (mean age 70.5 years, range 24–88) [26]. In their 2004 paper, Crossland et al investigated 7 early AMD patients (60–90 years, worse VA 1.3 logMAR (decimal 0.05)) who used 1 to 3 PRL [9]. In a consecutive paper [8] Crossland et al investigated patients older than 16 years affected by various pathologies some of whom used “multiple PRLs”. A fourth suggestion concerns possible differences in scotoma size.

Reading speed was not significantly improved after platform training as compared to the regular low vision rehabilitation program. Our hypothesis was based on the assumption that voluntary control of eye position would benefit from a multisensory rehabilitation program [25], although that study was not specifically concerned with gaze position. Other studies have failed to demonstrate a direct link between gaze stability and whole body stability [32].

Table 5
Pointing data before and after balance training in patients and control participants. Mean error to the target ± 95% CI

| Participants (all target locations) | Before platform training (mm) | After platform training (mm) | After low vision rehabilitation |
|---|---|---|---|
| Patients $N = 15$ | 7.86 ± 2.19 | 7.88 ± 1.76 | 7.09 ± 0.81 (1) |
| Controls $N = 13$ | 6.11 ± 1.63 | 5.42 ± 1.38 | |

(1) Two patients could not be retested after the rehabilitation.

Table 6
Mean number of PRLs and TRLs from a group of 13 patients who underwent complete platform training, as compared to the mean number of PRLs from the initial assessment of 38 patients who did not follow platform training. Mean ± 95% CI

| Patients | PRLs before platform training | TRLs after platform training |
|---|---|---|
| Platform training $N = 13$ | 3.47 ± 0.73 | 1.92 ± 0.50* |
| No platform training $N = 38$ | 2.63 ± 0.42* | |

*Statistically significant ($p < 0.05$).

Table 7
Reading speed before and after balance training and low vision rehabilitation (words per minute): Mean ± 95% CI

| Groups | Initial assessment | After platform training | After low vision rehabilitation |
|---|---|---|---|
| Controls (age-matched) | 174.77 | | |
| Patients on platform $N = 13$ | 27.07 ± 11.35 | 31.69 ± 14.30 | 46.5 ± 12.87 |
| Patients without platform $N = 41$ | 31.24 ± 9.56 | | 66.67 ± 9.92 |

Finally, visual dependency has been shown to be increased in elderly patients [3] but this did not affect our particular population of AMD patients. They were actually rather less dependent than their age-matched controls.

When the patients had reached a plateau with the low vision rehabilitation, the benefit of the rehabilitation was expanded to an optimum with the help of various optical and opto-electronic aids. These were magnifying glasses, spectacle magnifiers, telescopic systems, close circuit television or monocular optical aids according to the visual acuity and the distance to the object to be seen.

In conclusion, training on the platform significantly improved vestibular input in control participants and AMD patients by reducing their number of falls, but had no significant impact on reading performance of AMD patients. Our hypothesis that training the various sensory inputs would boost the benefits of the visual rehabilitation with the stabilization of a limited number of TRLs was only partially supported. Should this result be attributable to the limited number (5) of training sessions? In any case, there was a positive effect on vestibular control and reduction of falls. As such it appears as a useful tool to help with preventing some deleterious consequences of low vision and aging.

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