Combined use of several preferred retinal loci in patients with macular disorders when reading single words

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Abstract

To investigate the use of several preferred retinal loci (PRL) when attempting to read, two patients with bilateral central scotomas were asked to decipher single words, successively projected onto the retina using a scanning laser ophthalmoscope (SLO). Video-recordings of the fundus image, on which the projected targets were superimposed, were analyzed frame by frame. One patient used two PRL in association and the other used three, each PRL having a specific function. Single word reading made it easier than with full texts to correlate the images parts scrutinized and the retinal areas involved. Then, as patients were unable to describe their reading behavior, the examiner monitored refixation movements using the SLO and asked questions to help them to become aware of their reading behavior. Eventually, they could localize their PRL, describe their specific functions, and switch at will between them. © 1998 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Von Noorden & Mackensen (1962) observed that, with time and practice, patients with macular scotomas often develop a single, strongly preferred area for fixation outside the altered macular area. This new fixation area acts like a pseudo-fovea, taking over from the non-functional fovea the task of inspecting visual details and reading simple text; it is commonly called a preferred retinal locus (PRL) (Cummings, Whittaker, Watson & Budd, 1985). The PRL is usually located in an area immediately adjacent to the scotoma (Timberlake, Peli, Essock & Augliere, 1987; White & Bedell, 1990), in the lower part (Von Noorden, Allen & Burian, 1959; Weiter, Wing, Trempe & Mainster, 1984; Ohba, 1988; Acosta, Lashkari, Reynaud, Jalkh, Van de Velde & Chedid, 1991) and left part (Guez, Le Gargasson, Rigaudiere & O'Regan, 1993) of the visual field. However, there appears to be no simple rule by which it is selected; it can be located below, or to the side of the scotoma, or even in a spared area within the scotoma. It has been suggested that patients do not always choose a PRL in an optimal way (Timberlake, Peli, Essock & Augliere, 1987).

About one third of patients use several loci for inspecting a threshold acuity target (Cummings, Whittaker, Watson & Budd, 1985; Whittaker, Budd & Cummings, 1988). Whittaker, Budd & Cummings (1988) suggested that this might lead to the development of task-specific PRL, but they did not confirm this hypothesis. More recently, it has been shown that two loci may be used to identify two different targets (Guez, Le Gargasson, Rigaudiere & O'Regan, 1993; Trauzettel-Klosinski, Tornow, Teschner & Zrenner, 1995; Lei & Schuchard, 1997).

In this study, we investigated the reading pattern of single words in two patients with bilateral central scotomas. We analyzed the use of several PRL in these patients, using a scanning laser ophthalmoscope (SLO). We then evaluated these patients’ awareness of their defects and of their oculomotor behavior, with the aim of developing a new approach to rehabilitation based on their active participation. Finally, we investigated their ability to control their eye movements.
2. Method

2.1. Patients

We studied two patients (aged 47 and 82 years) with bilateral central scotomas. The younger patient suffered from Stargardt’s disease since the age of 16. His visual acuity was of 20/250 in both eyes. However, he used to read with monocular optic aids, choosing preferentially his right eye. The older patient suffered from an AMD since the age of 78. His visual acuity was of 20/160 in his left, better eye, which was regularly used for reading with monocular optic aids. Therefore, in this study performed under monocular conditions, we tested the right eye of the younger patient and the left eye of the older patient.

Our research conformed to the Declaration of Helsinki. Both patients gave their informed consent to the test procedures, and approval was obtained from the appropriate human experimentation committee.

2.2. Materials

We used an SLO (Webb, Hugues & Delori, 1987; Webb, 1990; Masters, 1994) from Rodenstock (Munich, Germany), with a program developed in our laboratory for projecting letters and words onto the ocular fundus. The image of the fundus superimposed with the image of the projected words, was displayed on a computer screen, and was video-recorded at a frequency of 25 Hz, using a U-matic magnetoscope.

2.3. Examination procedure

This consisted of two sessions of about 40 min each. In the first session, we performed a scotoma mapping using the SLO and software provided by Rodenstock. We then evaluated the spontaneous oculomotor behavior of the patients when reading single words. For this purpose, single words were projected in a random order onto the retina using the SLO. The smallest character sizes were selected according to the patient’s visual acuity. With the first patient, 28 words were projected, using seven different sizes of character, varying from 0.5 to 1.8° in height. With each character size, the words included one, two, five and ten letters. With the second patient, 25 words were projected, using five different sizes of character varying from 0.5–1.3° in height. With each character size, the words included one, two, four, six, and ten letters. The font was ‘Times New Roman’. Video recordings of the examinations were analyzed frame by frame as follows. The borders of the scotoma, optic disc, and main vessels were first outlined onto a sheet of transparent paper. Then, for each successive frame of the videotape, the position of the projected word relative to the fundus structures was plotted onto the paper.

In a second session, we evaluated the patients’ awareness of their scotomas and of their oculomotor behavior, and their ability to control their fixation pattern.

To investigate scotoma awareness, the patients were first asked to describe their visual defect. The borders of the scotoma were then delineated onto an Amsler grid, using a white 5 mm visual target seen from a distance of 30 cm, in a tangent screen type of examination.

Next, using the SLO, and to evaluate the patients’ awareness of the locations and functions of the PRL, we asked the patients to describe their reading pattern with regard to the scotoma position, during their deciphering attempts. We then asked more specific questions, like the following: ‘Did you realize that you just changed your eye position? What did you do? Try again looking at the word in different ways, and pay attention to what you are doing?’; ‘Did you realize that you used different fixation positions around your scotoma?’; ‘Right now, how is your fixation? Which letters are you able to recognize when looking at this position?’; ‘How does the present fixation position differ from the last one?’

Finally, in an attempt to increase their control of their reading strategy, when aware of their PRL locations, the subjects were asked to switch from one PRL to another.

3. Results

The results of scotoma mapping are shown in Fig. 1. Analysis of spontaneous oculomotor behavior showed that patient 1 mainly used a combination of three PRL to read single words. One PRL was located just above the main lesion (the upper PRL); another was located to the left of the main lesion (the left PRL); and the remaining PRL was to the right of the main lesion (the right PRL). To read the great majority of the words, he used the upper PRL associated with at least one of the two others PRL (Fig. 2). Superposition of letters on the fundus image and location of the scotoma borders showed that, when using the upper PRL, the whole word was projected beyond the scotoma borders, whereas when using the left PRL, only the first letters of the word were outside the scotoma area and when using the right PRL, only the last letters of the words were outside the scotoma borders (Fig. 3). Without exception, patient 1 used the upper PRL for the initial fixation of words. When switching from one lateral PRL to the other lateral PRL, he transiently projected the word onto the upper PRL two times out of three.

Patient 2 used two PRL to decipher single words. One PRL was located at the left border of the main lesion (the left PRL), and the other PRL was located just above the main lesion (the upper PRL). To read
Fig. 1. Scotoma mapping using the SLO. Visual field defects delineated with the Goldman IV size target are shown in dark gray, and those delineated with the Goldman II size target are shown in light gray. Locations of the center of the fixation cross recorded at each presentation of the Goldman targets are shown by dots. The shape and relative size of the fixation cross are shown in the top right corner of the figures.

shorter words, he used the left PRL, whereas to read longer words he used his two PRL in association (Fig. 4). Superposition of letters on the fundus image, and location of the scotoma borders showed that, when using the upper PRL, the whole word was projected beyond the borders of the scotoma, whereas when using the left PRL, only short words were visible in their entirety, longer words being visible only in segments (Fig. 5).

When asked about the nature of their visual defect, both patients at first appeared to be unaware that part of their visual field was missing. They only believed that there was an area of their visual field in which vision was less clear. A scotoma was then demonstrated, using a tangent screen type evaluation, at which time the patients realized that they had a blind area in their visual fields. By describing the completion phenomenon, the examiner explained to the patients why they were unaware of their scotomas in everyday life.

Using the SLO, the patients were questioned about their fixation position with regard to their impression that they were looking straight ahead during reading attempts. Both patients were at first unable to answer. The examiner then asked specific questions while the fixation position was monitored with the SLO, and both patients became progressively aware of the location of their PRL. This occurred in three stages.

In the first stage, lasting about 3 min, when describing his reading pattern, patient 1 first stated that he was ‘moving his eyes’. Then he realized that he was ‘using a visual area located below’ (his scotoma). At this stage, patient 2 observed that his gaze was directed to the right.

In the second stage, lasting about 15 min, the investigator helped the patients with verbal instructions to position their different PRL successively onto the projected words. Both patients managed to stabilize the word image onto each PRL in turn, and eventually both patients became aware of these visual areas.

In the third stage, after about 5 min of training, the patients were able to switch at will from one PRL to another, at first helped by verbal instructions from the investigator, then on their own. At this stage, both patients discovered the specific function of each PRL. The first patient stated: ‘In the right position, I can see...’

Fig. 2. Locations of the PRL used by patient 1 when reading single words. Irrespective of size of characters or length of words, the upper PRL was consistently used in combination with one or two of the others PRL, except for the longest words in the two largest characters, where only the upper PRL was used. When the patient could not decipher the projected word, no results are indicated. Use of the right PRL is shown by white boxes; use of the left PRL is shown by dark gray boxes; use of the upper PRL is shown by light gray boxes.
Fig. 3. Example of successive retinal loci used by Patient 1 to read a single word. Superposition of the word on the fundus image with corresponding scotoma borders showed that, when using the upper PRL, the whole word was projected beyond the dense scotoma borders (1, 4 and 6); whereas when using the left PRL, only the first letters of the word were outside the scotoma borders (2, 5 and 8) and when using the right PRL, only the last letters of the word were outside the scotoma borders (3, 7 and 9). Visual field defects delineated with the Goldman IV size target are shown in dark gray, whereas those delineated with the Goldman II size target are shown in light gray. In this example, characters of the presented word (‘fraternité’) are 1.2° in height.

The beginning of the word; in the left position, I can see the end of the word; in the upper position, I can see the whole word but less clearly. When I use all three positions, I can read the word.’ The second patient said: ‘In the upper position, I can see the whole word, whereas in the lower right position I can see the word better, but in segments.’

Thus, the results of the patients’ own analysis of their reading strategies corroborated our previous findings, based on the analysis of our video-recordings. Our observations suggested that spatial resolution was higher in the PRL where the words were seen by segments, compared to the other PRL, in which the whole word was visible but resolution was lower.
Fig. 4. Locations of the PRL used by patient 2 when reading single words. Thirteen out of 14 times, to read single words of four letters or less, the patient consistently used his left PRL alone. In contrast, with longer words, he used his left PRL in combination with the upper PRL four out of five times. When the patients could not decipher the projected word, no results are indicated. Use of the left PRL is shown by dark gray boxes; use of the upper PRL is shown by light gray boxes.

4. Discussion

Our results showed that patients can use several PRL in combination to read single words. Moreover, during monitoring of the fixation pattern using the SLO and a verbal interaction with the examiner, patients can become aware of their use of several areas of the visual field to decipher a word. Eventually, they can localize these areas in relation to their scotomas and describe the specific functions of each PRL. Following training, our patients were able to switch at will between their different modes of fixation.

Both patients used a combination of a PRL offering a global viewing of the word, and one or two other PRL giving a higher spatial resolution but a visual span limited on one side by the scotoma.

Patient 1 used the upper PRL for a first viewing of the word, and two other PRL of higher resolution, in which the words were partially masked by the scotoma. Two times out of three, he transiently used his upper PRL when switching between his two lateral PRL. This apparently allowed him to localize the word in its entirety.

Similarly, patient 2 used his left PRL in association with his upper PRL to read long words that could not be viewed in their entirety using the left PRL. This suggests that the left PRL provided sufficient vision to read only short words. To read longer words, the upper PRL may have offered a wider span compared with the left PRL, which gave better spatial resolution but was limited to a visual span of three or four letters. In contrast to patient 1, patient 2 used no PRL on the right side of the lesion, probably because the lesion extended further to the right than in patient 1.

Up to now, it has generally been accepted that patients who are well adapted to their defect have developed an oculomotor behavior based on a single PRL, which is well-defined and well circumscribed, and used to perform tasks requiring fixation. It has been suggested that this is associated with a change of the coordinates of the retinomotor center from the non-functioning fovea to the newly developed PRL (White & Bedell, 1990). White & Bedell (1990) showed that about one third of their patients developed this well-adapted oculomotor behavior. More recent studies, however, have shown that one retinal area located inside a preserved area of the scotoma can be used to identify small targets, and another PRL, eccentric to
the scotoma, to identify larger ones (Guez, Le Gargasson, Rigaudiere & O’Regan, 1993; Trauzettel-Klosinski, Tornow, Teschner & Zrenner 1995). Moreover, an eccentric fixation area can shift according to stimulus illumination (Lei & Schuchard, 1997). Our study also showed that several PRL can be used in combination to perform a visual task. Such an adaptation does not involve a shift from the fovea to a new retinomotor center, but a combined use of different PRL according to their visual abilities. Up to now, it has generally been accepted that patients who have developed only one PRL must choose between an area with a better resolution ability, and one with a more useful field of view (Timberlake, Mainster, Peli, Augliere, Essock & Arend, 1986; Timberlake Peli, Essock & Augliere, 1987). Our observations, however, show that these different PRL can be used in association to perform a single visual task.

Whereas our patients used two or three PRL for deciphering projected words, they used a single PRL during scotoma mapping, for looking at the fixation cross. This showed that the number and location of the PRL may change from one task to another, at least when the visual abilities required to perform the tasks are different.

It has been suggested that, when patients have a central scotoma in each eye, the monocular characteristics of PRL cannot always be extrapolated to binocular viewing tasks (Schuchard & Fletcher, 1994). For technical reasons, we performed our study under monocular conditions. However, both patients tested in our study used to read in daily life under monocular conditions. In our experimental setting, they presumably employed their usual PRL and associated gaze strategies.

To study the reading patterns of patients with central scotomas, we first investigated eccentric fixation while attempting to decipher single words, rather than a full text. This makes it easier, when analyzing fundus SLO recording, to recognize the image area to which attention is being paid. It also makes it easier to correlate the part of the image being scrutinized with the retinal areas involved. Similarly, when analyzing subjects’ verbal comments on what they are experiencing, having the subject read the word aloud can give more precise information on the reading process when deciphering single words.

Even if the information obtained from an examination procedure using isolated words cannot be simply extrapolated to reading a full text, nevertheless the observations it provides are invaluable. Thus, it has been observed that, in patients with macular disorders, frequent regressions and vertical saccades occur when reading texts (Trauzettel-Klosinski, Teschner & Tornow, 1994). Our findings suggest that analysis of single word reading is useful in determining whether such movements, thought to be uneconomic, can in fact reflect purposeful changes of PRL.

It has been recognized that previous rehabilitation methods based on an empirical training of eccentric viewing, are beneficial (Bäckman & Inde, 1979; Goodrich & Mehr, 1986; Nilsson & Nilsson, 1986; Peli, 1986; Nilsson, 1990; Nilsson & Nilsson, 1994). However, the results of our study lead to an alternative approach to rehabilitation, in which the use of one or several PRL may be considered. The therapist and the patient, together, will attempt to define oculomotor behavior that is more appropriate for specific visual tasks. This approach involves evaluating the location and function of each possible PRL, using the SLO, and visualizing the patient’s oculomotor behavior in real time, while directly interacting with the patients.

The patient might participate better in his rehabilitation process if aware of the presence and location of his visual field defect. Few studies have been performed on patients’ perception of, and adaptation to, their defect. It has been established, however, that affected subjects are usually unaware of, or underestimate, their scotoma and have little understanding of their oculomotor behavior (Schuchard, Fletcher & Maino, 1994; Schuchard, 1995; Fletcher & Schuchard, 1997).

Unawareness of the scotoma is due to cerebral plasticity, resulting in a cortical reorganization following local deafferentation. It results in a filling-in of the missing information when part of an image falls on a scotoma (Ramachandran & Gregory, 1991; Safran & Landis, 1996). As a result of filling-in, delineation of the scotoma using an Amsler grid is unreliable compared to the tangent screen examination (Achard, Safran, Duret & Ragama, 1995). In the present study, we therefore paid special attention to first making the patients understand the nature of their visual impairment.

We then found that patients could become aware of, and to some degree control, their oculomotor behavior. Interestingly, our second patient, who was affected late in life, demonstrated a sensory motor adaptation to his visual defect similar to that of the subject affected from youth. Our preliminary analysis of the video recording was found invaluable in formulating appropriate questions to the patients, and in helping them to define the locations and functions of their PRL.

In this study, we analyzed in detail the oculomotor behavior patterns in two patients. We did not attempt to evaluate the rates of occurrence and use of several PRL in the population. Further studies are needed to determine the proportion of patients showing such a reorganization in their oculomotor behavior when reading, and a comparable ability to understand and control their fixation pattern. This should lead to further improvements in rehabilitation.
References


