

Visual field enlargement by neuropsychological training of a hemianopsia patient*

G.J. VAN DER WILDT & D.P. BERGSMA

VISIO RINH, National Foundation for the Visually Impaired and Blind, Paasheuvelweg 17, 1105 BE Amsterdam-zuidoost, The Netherlands

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Abstract. A 58-year old hemianopsia patient was submitted to a two-fold neuropsychological training in order to enhance visual functions in the affected part of his visual field. At first, the visual field was measured perimetrically, to serve as a starting measurement with which after-measurements could be compared. Then, the first training was started: the border area between the intact and the defect visual field was being stimulated by small light spots. The training consisted of repetitive detection threshold measurements. After 27 one-hour sessions, the visual field was being measured again. The visual field appeared to have been enlarged 5 to 12 degrees in the direction of the affected hemifield and contrast-sensitivity thresholds to have been decreased almost at every point in the stimulus-array. Then, a second training started; an eye-movement training. Again, the border area, now shifted outwards, was stimulated. This time, the stimulus concerned a short presentation of light (< 200 msec.) after which the subject, to the best of his abilities had to make an eye-movement to the perceived stimulus-site. Also, he had to categorize the quality of his perception as well as the direction in which the stimulus was thought to be perceived. After 30 sessions, the visual field appeared to have 'grown' just a little bit more, but this seems not to be a significant enlargement. More important, the number of detected stimuli in the supposed 'blind' area had increased, as had the accuracy of the localization of the stimuli. Preliminary results of the detection training of a second subject, also 58 years of age, are presented. Finally, planned actions are discussed.

Key words: hemianopsia, low vision, rehabilitation, training, visual field

Introduction

Homonymous hemianopsia is a visual restraint, caused by some types of brain damage, in which half of the visual field is 'blind' (hemianopsia), for both eyes to the same extent (homonymous). This last description makes it very typical for the damage to be cerebral, since the distribution of visual neuronal pathways after the chiasm provide both hemispheres with the same amount and type of information from both eyes. Although the term hemianopsia indicates two kinds of visual fields: intact and blind, literature shows, that with (homonymous) hemianopsia the transition of the intact visual field into the defect visual field is a matter of an area, rather than a distinct borderline.

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In this area, perception is distorted, but not totally absent; perception of simple light stimulation in this area seems to be a matter of chance. Near the intact field, stimuli may be detected, e.g. 9 out of 10 times; near the 'blind' area, this rate might be 1 out of 10 [1–5]. But even in the 'blind' areas, residual visual functions, as for example the detection of movement [6] or the detection of flashlight stimuli [2, 7] might still be present. The notion of blindsight might be viewed in that light. It has also been made clear, that attention plays an important role in perception. Stimuli, not detected when presented at a random point in the visual field, may be seen when presented at a predesignated spot. Also, attentional deficits after brain-damage appear not to be absolute; often there are some attentional capabilities left [8–10]. Since, in other words, there is still visual activity in these supposedly 'dead' brain areas, it might prove interesting to find out whether or not these residual visual functions are trainable.

Therefore, we submitted our subjects of this study, RS and LV, to a number of training sessions during which different types of visual stimulation was presented, and investigated any change in their visual performance. The program was completed for RS. For LV, the program was recently started, and preliminary results are presented.

Subjects and methods

Material

A Tübinger perimeter was used both for the measurements of the visual fields (before and after the training), and for presenting the stimuli during the training sessions.

The first subject

RS, male, 58 years, no previously known cerebral deficits, suffered from a CVA at age 56. Neurological investigations showed the presence of an aneurysm in his right posterior cerebral artery, which had to be dealt with in surgery, after which RS was left with a leftsided paralysis and a leftsided hemianopsia. The paralysis was rehabilitated until mobility was reasonably well, but the sensory modality of the complete left side of his body will always remain slightly damaged. Visual acuity was 1.33 (ODS).

The second subject

LV, female, 58 years, no previously known cerebral deficits, suffered from a post-operative CVA after the surgical removal of a tumor at age 56. This resulted, amongst others, in a quadrantanopsia in the upper-right visual field. Visual acuity was 1.2 (ODS).

The training program

The training program consisted of two different types of training.

Detection training

In fact this was a repetition of detection threshold measurements, according to the method of static perimetry. Thus, while the subject was fixating his gaze on a spot of light in the center of the Tübinger sphere, stimuli appeared in several predesignated locations in the visual field. Stimulus light intensity was modulated through four categories of luminance contrast (against the background). The subject had to give a response when he or she detected a stimulus, which was confirmed by the subject's report of the perceived stimulus-site. The aim was to see if the function of detection was trainable so that the functional visual field would enlarge.

Eye movement training

Again, the subject had to fixate his/her gaze on the central spot of light. This time, a flashed stimulus was presented, towards the location of which the subject had to make an one-sweep saccade. The aim was to see if the quality of the eye-movements themselves were trainable to become more like a reflex. The size and the intensity of the stimulus were kept constant. The presentation time was less than 200 msec. By presenting the stimulus this short, it did not exceed the latency of a saccade, so that the subject didn't just search for the stimulus with central vision, which was intact. The rationale for this is, that we wanted to find out how peripheral processing of light was affected. If in the affected cortical areas there would still be some form of visual functioning, which might be so [6], then this residual functioning might be trainable. Besides an eye-movement, the subject had to give a verbal response of detection, as in the detection training.

For the eye-movement training it was obviously necessary to obtain reliable eye-movement parameters like speed, direction and number of saccades. Unfortunately, we were unable to obtain steady, reliable measurements of the eye-movements during the training sessions. Initially, we tried to measure the eye-movements with the so-called 'IRIS-spectacles'. This device basically measures the ratio of the infrared light, reflected from the iris and the white part of the eye. The trouble with this method is, that registration of eye-movements in the vertical and in the horizontal direction are not independent. This makes determining the position of the eyes insufficient accurate. But although eye-movements were not recorded during each training session, we nevertheless instructed the subject to make an eye-movement to the perceived stimulus location. Besides this, the subject had to report the meridian on which the stimulus was presented, by naming 'clock-numbers' (e.g. middle left is

nine o'clock) to check whether or not a detection was a 'real' one. We used the parameter 'percentage adequate localization' to see if the proper location of the stimulus could be detected. If the subject had not detected anything, he or she had to guess in what location the stimulus had been presented. By comparing 'percentage adequate localization' with 'percentage of detection' we wanted to see if the notion of 'blindsight' was supported in this case.

Finally, we wanted to find out what the possible interacting role of attention might be. Therefore, we presented the stimuli under two conditions: MA, in which the subject knew on what meridian the stimulus would appear; ZA, in which the subject was not given any information about the stimulus location. We hypothesized detection would be better in the MA condition, where all attention could be dedicated to a particular area of the visual field, instead of having to divide attention between several areas, as was thought to be necessary in the ZA condition.

Parameters

Independent parameters

For the detection training, the diameter of the stimulus was 44 min of arc. The four stimulus intensities had a contrast against the background of 3.5%, 10.5%, 31.5% and 94.5%, respectively. Contrast is defined as

$$C = \frac{\Delta L}{L}$$

where L is the background luminance and ΔL is the increment luminance of the stimulus. The diameter of the fixation point was 30 min of arc, its contrast was 5%. The stimuli were presented on predetermined locations in the border area (see Figure 1). These locations were chosen with the knowledge that enhancing effects should be best in this area [1–2]. For the eye-movement training less locations were included, but they were used several times for stimulation. The stimulus diameter was 100 min of arc and had a contrast of nearly 100% all the time. As mentioned before, and as can be seen in Figure 1, in the eye-movement training stimuli also covered areas more peripherally to find support for 'blindsight'.

Dependent parameters

A baseline visual field was determined before the training by means of binocular dynamic perimetry. For subject RS, this was done for 25 different meridians in the left visual field, i.e. from 90° to 270° with a 7.5° interval. For subject LV, this was done for 15 different meridians in the upper right visual field, i.e. from 352.5° to 97.5° with a 7.5° interval. Each meridian was

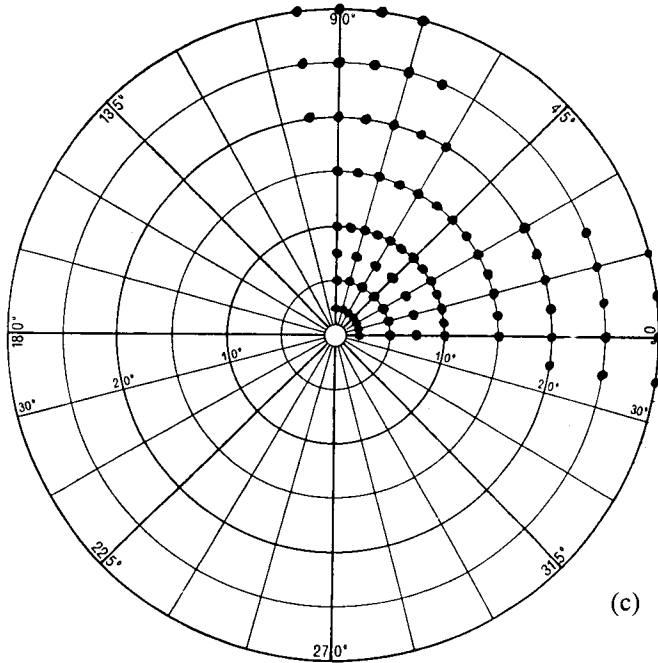


Figure 1. Continued.

measured five times and the obtained average values made up the outline of the visual field. Next in the detection training we measured the detection thresholds of the stimuli. For the eye-movement training, we determined the percentage of detections as a function of session-number in the conditions MA and ZA. Also, the percentage of correct localization of the stimuli as a function of session-number was determined.

Results

Figure 2 depicts detection as a function of session-number in the detection training of subject RS.

As can be seen, the percentage detections increased from 61% to 90%, and the percentage detections of the lowest but one contrast stimuli ($C=10.5\%$) increased from 0% in the first three sessions to 66% in the last session.

The results from the eye-movement training are shown in Figures 3, 4 and 5. The percentage detections in the 'With Attention' (MA) condition (Figure 3) shows a fairly 'quiet' increase, whereas performance in the 'Without

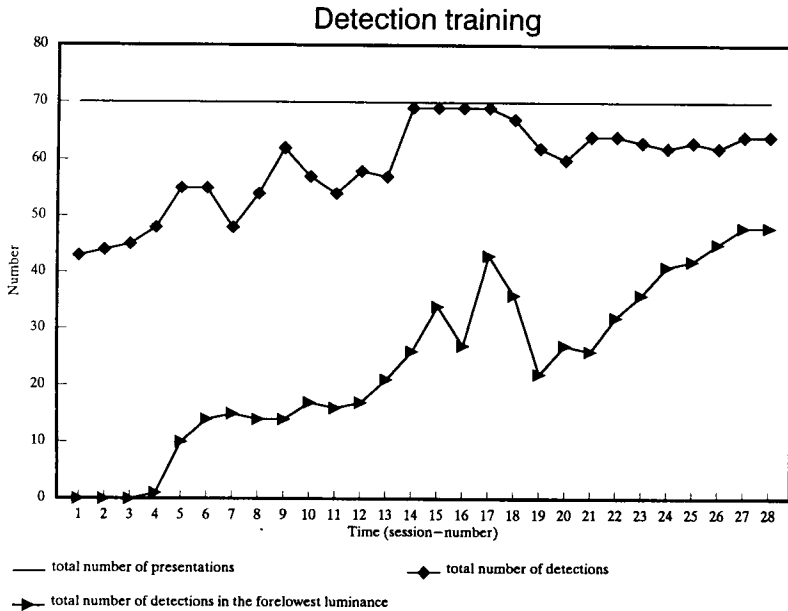


Figure 2. Detection as a function of session number. Upper curve: number of presentations; middle curve: total number of detections; lower curve: number of detections of low contrast stimuli. Subject RS.

Attention' (ZA) condition (Figure 4) seems to have more variation. However, in the ZA condition, there is as much improvement as in the MA condition.

We also asked the subject to point out the meridian on which the stimulus was presented, by naming the corresponding time on a clock. Figure 5 shows, that the localization of stimuli becomes better in time, which is in concordance with the increase in percentage of detections (Figures 3 and 4). As can be seen, the percentage of adequate localisation appears to be significantly better than the number of detections.

Finally, we wanted to investigate what the effects of the training program would be for the visual field, as it was measured by means of binocular kinetic perimetry. Figure 6 shows the visual field of subject RS just before the start of the training program, after several learning sessions. Figure 7 depicts the visual field after the training program had been finished. The shaded area represents a formerly affected part of the visual field, which is now functional. As can be seen, the transition between the intact and affected field has shifted 5 to 12 degrees towards the periphery. In other words, the functional visual field has been enlarged.

As mentioned in 'Introduction', we recently started the program for a second subject, LV. As can be seen in Figure 8, preliminary results from 17

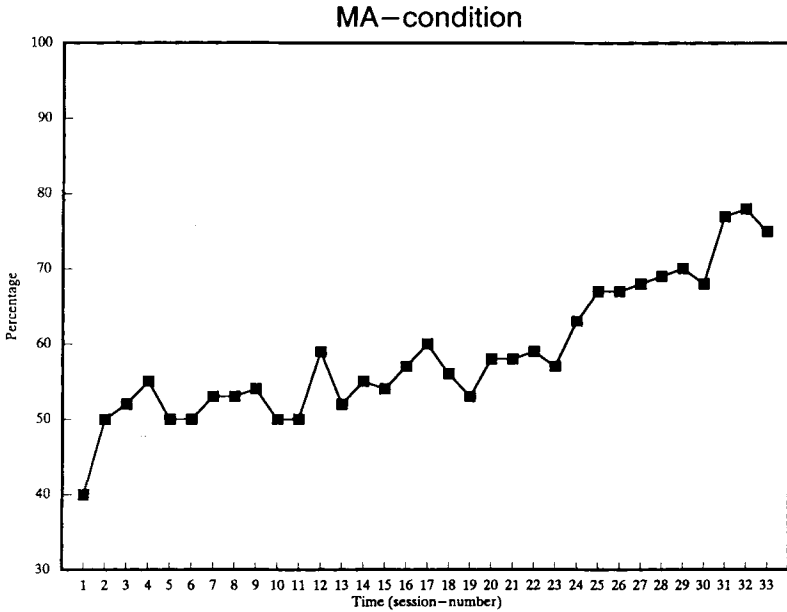


Figure 3. Percentage of detections as a function of session number in the MA condition of the eye-movement training of subject RS.

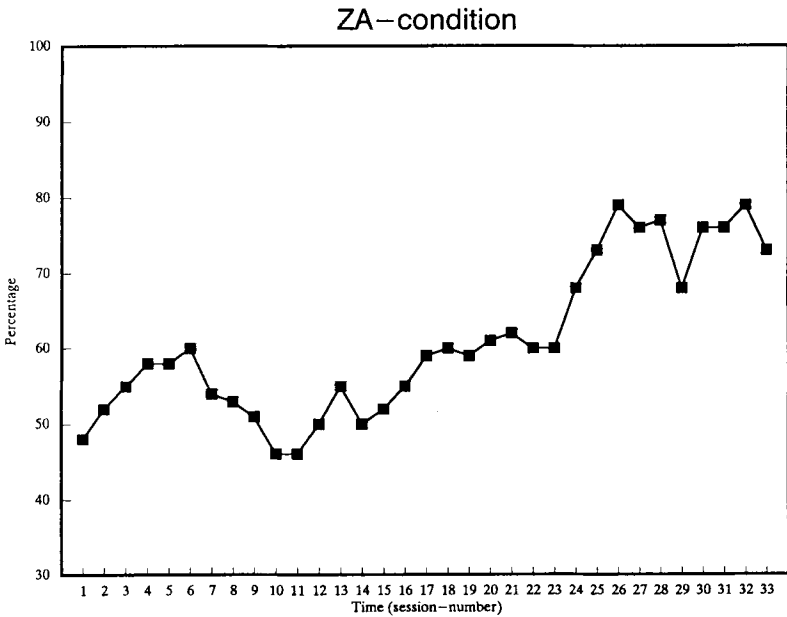


Figure 4. Percentage of detections as a function of session number in the ZA condition of the eye-movement training of subject RS.

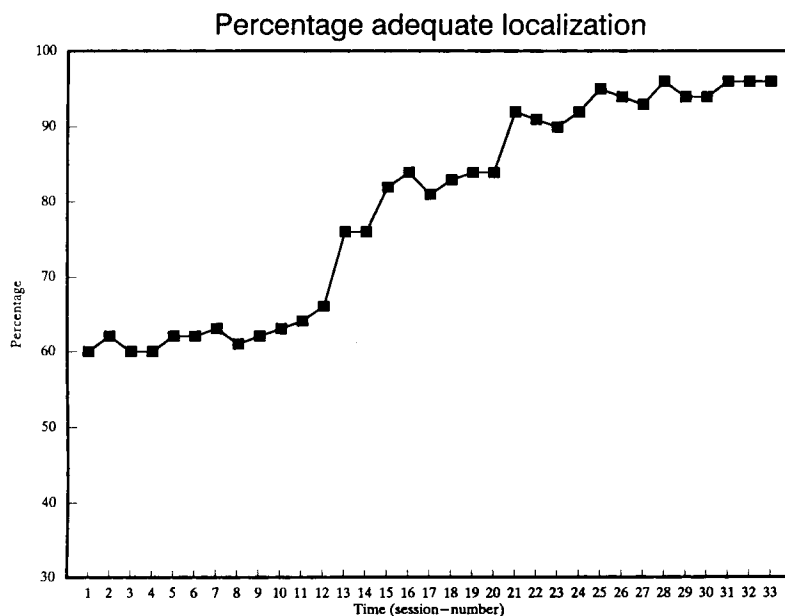


Figure 5. Percentage of adequate stimulus localization as a function of session number in the eye-movement training of subject RS.

sessions of detection training indicate a similar trend as with subject RS: percentage detections went up from 40% to 84% and percentage of detection of 10.5% contrast stimuli went up from 0% in the first two sessions to 31% in the last session.

Discussion

In all training situations, an improvement of the performance was found. The training started 20 months after the operation of subject RS, so natural recovery as an explanation for the increase in detection can be ruled out. Also, the contrast level a stimulus was detected on, seemed independent from the time intervals between sessions. Once a stimulus on a certain location was detected at a certain contrast level, detection tended to remain on or even top that level, whether training was restarted the following day or nine days later. If detection of that same stimulus suddenly took place on another contrast level, it would almost invariably be on a lower contrast level and it would, with a few rare exceptions, stay on that level. Some of the stimuli, situated in the border-area were not detected in the beginning, but were detected after a few sessions at a high contrast (94.5%), then at a lower contrast (31.5%) and,

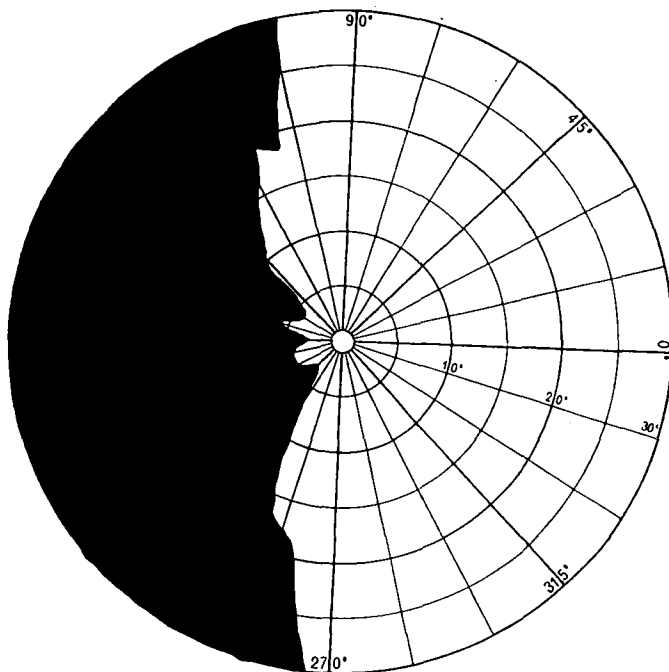


Figure 6. The visual field of subject RS before training.

finally, at a still lower contrast (10.5%). These results appeared to be stable after a check up two months later.

The total number of detections and the number of detections of the lowest but one contrast stimuli (10.5%) as a function of session-number are shown in Figure 2. The reason for this last measure is, that it gives some more information about the contrast level at which stimuli are detected. The total number of detections only tells us whether or not a stimulus was seen. Of course, the 10.5% contrast detections are a subset of the total number of detections. The lowest contrast stimuli (3.5%) were hardly ever detected.

Figure 2 clearly shows an increase in the percentage of the presented stimuli that is detected. By closer examination, contrast sensitivity proved to have been increased at almost every point of the stimulus-array (64 out of 70). The increment varied from 1 to 3 steps through the contrast categories.

The preliminary results of the second subject (LV), are given in Figure 8. This figure shows the same kind of increment for both total percentage of detections and percentage of detection of the low contrast stimuli. These results suggest an improving effect by the training on the detection thresholds in the affected areas.

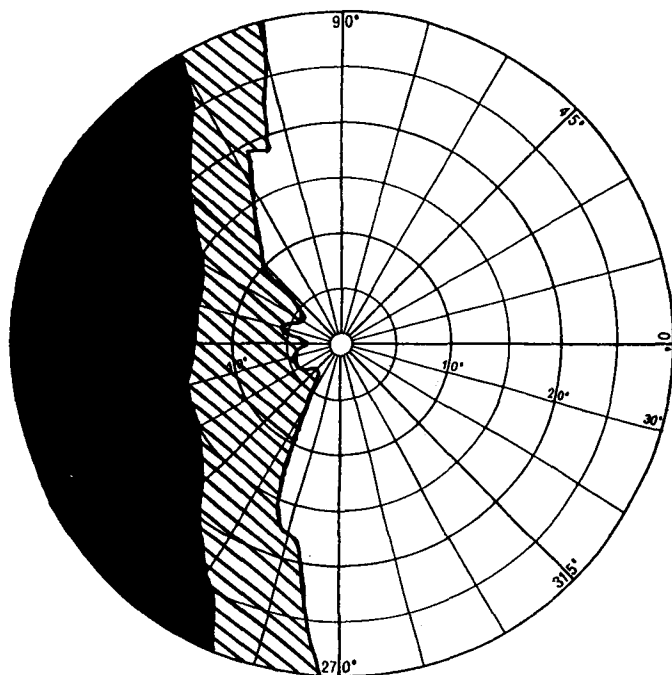


Figure 7. The visual field of subject RS after training. The shaded area belonged to affected visual field before the training, but became a functional part of the visual field after the training.

The results of the eye-movement training again show an increase of percentage of detection for both the MA and the ZA condition. However, at the end of the training there is no real difference between the two conditions. Either attention makes no difference, or the concept of 'attention' has not been made operational properly. The last option seems the more likely, if one realizes, that for RS, the ZA condition was not altogether without any information: attention could be restricted to the left hemifield, since there were just a few stimuli in the right hemifield which would immediately be detected without attention directed to it. The percentage of adequate localization of the stimuli can be seen to have increased from ca. 50% to 75%. Closer comparison of Figures 3 and 4 with Figure 5 reveals, that the percentage adequate localization is some 15% - 20% higher than the percentages of detection in both conditions. Not only is this in support of detections being 'real' and most of the indications of stimulus location being correct, but it also is a positive indication of 'blindsight'.

The most conspicuous result can be seen in Figures 6 and 7. The visual field, measured by means of binocular kinetic perimetry, appears to have been enlarged 5 to 12 degrees in the direction of the affected, left hemifield. This

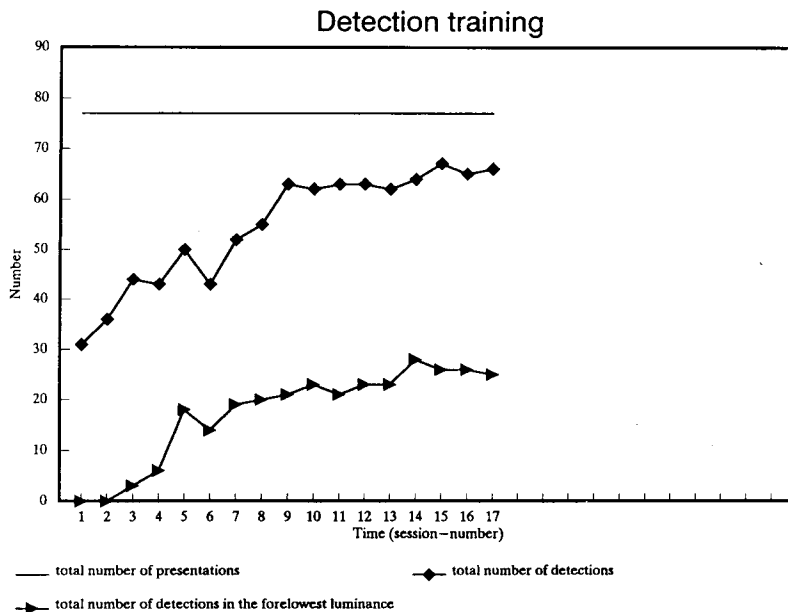


Figure 8. Detection as a function of session number. Upper curve: number of presentations; middle curve: total number of detections; lower curve: number of detections of low contrast stimuli. Subject LV.

result is only reliable, if can be shown, that during the relevant moments of the perimetry, the subject was fixating correctly. As mentioned before, we were unable to obtain reliable eye-movement parameters from the eye-movement training. As an alternative to the IRIS-spectacles we were able to apply the Robinson-method [11]. This method is based on the voltage that is induced in a coil, placed in an alternating magnetic field. The coil is mounted in a silicon rubber contact annulus. The annulus is fitted around the iris of the eye. Although the method is very adequate in recording eye-movements, it proved far too stressful for our subject to apply during each training session. However, it is of course very useful for observing the steadiness of the subject's fixation during kinetic perimetry. This should indicate whether or not the found enlargement of the visual field was partially or even totally caused by eye-movements. Therefore we measured the eye movements of subject RS during only one kinetic perimetry session. Figures 9a and 9b show the fixation movements of the eye during the 5 seconds before the detection of an incoming stimulus (in the affected area) at 12.5° left of the fixation point and 5.5° below it. Figure 9a is the XY-diagram, while 9b shows the same data in a Xt-diagram. The pulse at the side of Figure 9b marks the moment of detection. As can be seen from Figure 9a, the fixation stays within half a

degree from the center of the fixation point, which by itself was an area of about 1 degree diameter. Also before other detections of stimuli in the affected hemifield, the fixation movements stay within 1° from the fixation center. Also the directions of the eye movements were not correlated with the position of the detected stimulus. This shows that during kinetic perimetry, fixation was reasonable well. Stimuli presented in the left hemifield, at eccentricities of more than 10° , were detected, while eye-movements did not exceed 1° . So, the found visual field enlargement of 5° to 12° cannot be accounted for by unallowed eye-movements.

As mentioned before, the stimulus locations were chosen where they were thought to have the maximum effect. As can be seen, there is a concordance between the locations of the stimuli (Figure 1a) and the area of the visual field, where we found an effect of the training (shaded area in Figure 7).

We were able to obtain an EEG-registration of subject RS, while performing a simple visual task. Figure 10 shows a fragment from these measurements. What can be seen in this figure are VEP's, which in the right hemisphere of the brain (P4, T6 and C4) are still recognizable as visual activity, when compared with the normal, left hemisphere activity (T5, P3 and C3). The codes stand for electrode locations, which are related to both the intact and the affected visual field. It might be very interesting to find out, if these VEP measurements could serve as criteria for selecting subjects who could benefit from this training.

There seem to be good reasons to conclude, that homonymous hemianopsia, a cerebral blindness, is trainable and that this may lead to an enhanced parafoveal detection, which widens the visual field and to an enhanced localization of peripheral stimuli. These results concur with literature [1–3, 5, 6, 12]. In our opinion training programs like these could lead to successful rehabilitation programs. Of course, it is therefore important, that the found increase is also a functional enhancement in the daily-life situation. Our subjects proved to be very happy with the results of the training [13], actually more than we expected after seeing the results. At the moment an objective measurement of this is lacking. In the future it might be very interesting:

- . to have more hemianopsia cases;
- . to have criteria for what people can be trained, and, if there are any, what people cannot be trained;
- . how the procedures themselves could be improved;
- . to include valid eye-movement measures;
- . to investigate more closely the transfer to daily-life situations (e.g. reading) and to minimize experimenter's bias

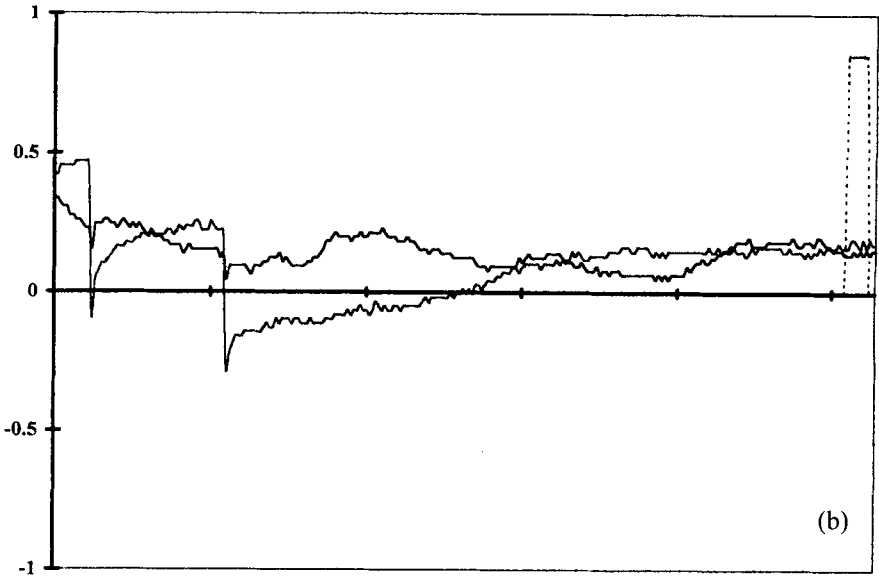
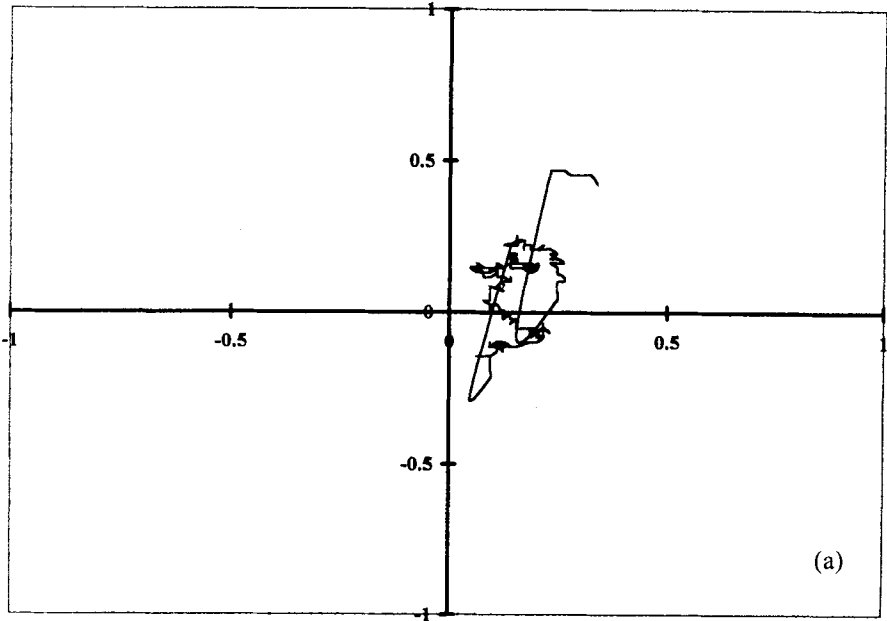


Figure 9. An example of the fixation movements, measured during perimetry with the Robinson-method. (a) The eye movement, in degrees, around the fixation point during a 5-second interval prior to detection of a stimulus in kinetic perimetry; (b) The same data as a function of time.

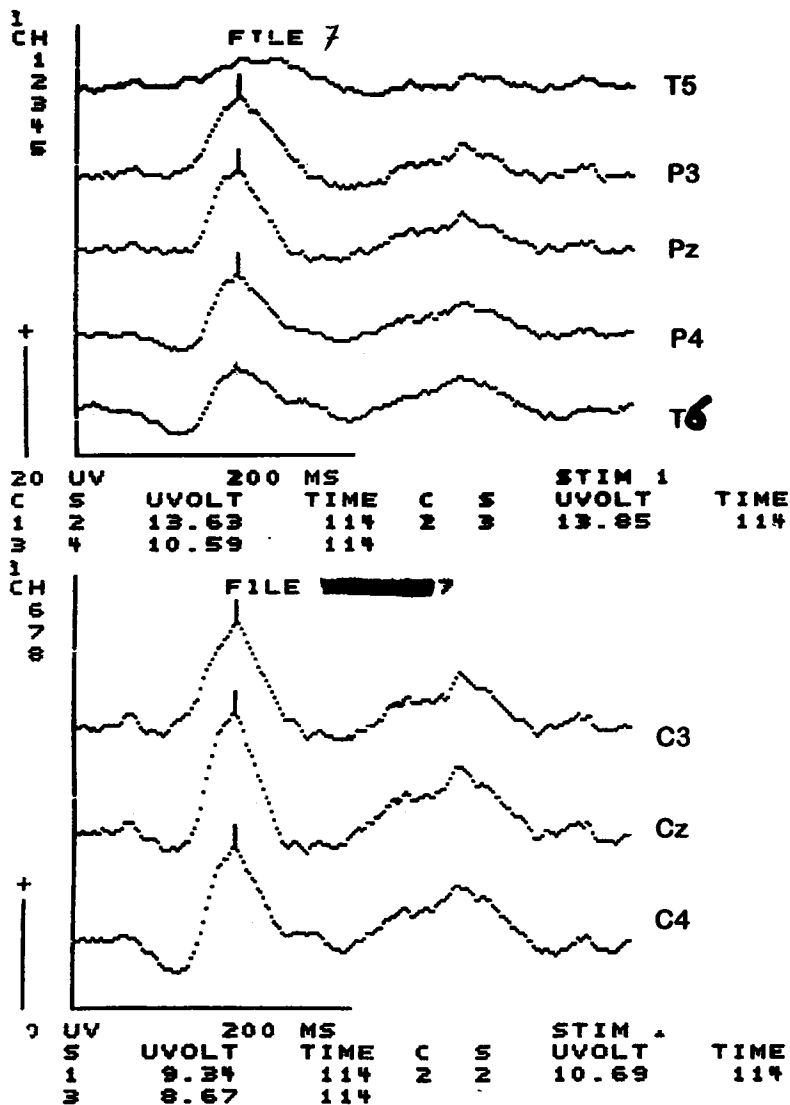


Figure 10. Fragment of EEG-measurement (VEP's) of subject RS, while performing simple visual task.

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Address for correspondence: G.J. van der Wildt; D.P. Bergsma, Neuro-ethology, University of Utrecht, Limalaan 30, 3584 CL Utrecht, The Netherlands
Phone: +31 (0)30 253 3944; E-mail: g.van.der.wildt@www-vf.biol.ruu.nl