# Temporal dynamics, sensitivity and form discrimination in blindsight

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# Temporal dynamics, sensitivity and form discrimination in blindsight

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# Table of contents

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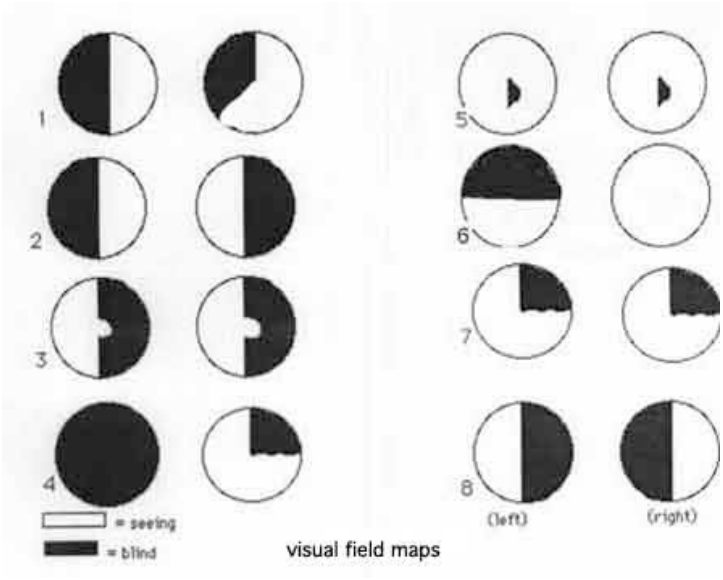
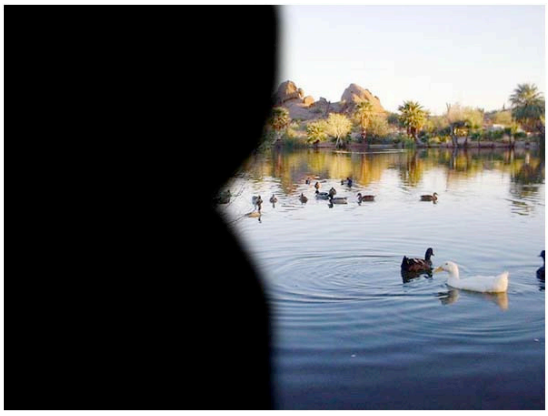
# CHAPTER I:
# General Introduction

## General definition of blindness

Beside retinal blindness (by diverse optical diseases or damage to the retina) there are forms of blindness arising due to damage to parts of the primary visual cortex (V1, striatum, striate cortex or Brodmann area [BA] 17). These may arise due to stroke, accident and neuronal degeneration, which can result in more or less impairment of visual capacity and in the loss of parts of visual field. The generic term for this loss is anopia[1]. In terms of visual space and related to the dimensions and location (before or after the optic chiasm) of the damaged tissue, visual field losses can be of different size: from the restricted loss of a small area of visual field, which is referred to as scotoma, up to quadrants (referred to as quadrantanopia), or even half fields (referred to as hemianopia). Hemianopia can be homonymous (corresponding left or right visual field) or heteronymous (bitemporal or binasal hemianopia), depending upon the exact location of the lesion. Visual losses are located in the visual field contralateral to the site of the lesion. Their dimensions can even extend to a complete visual field defect (and therefore complete blindness) when brought about by large bilateral lesions to primary area of occipital cortex.

[1] Anopias = the inability to see, the totally or partially loss of vision, as in scotoma, quadrantenanopias and hemianopias, ICD-10 H53.4.



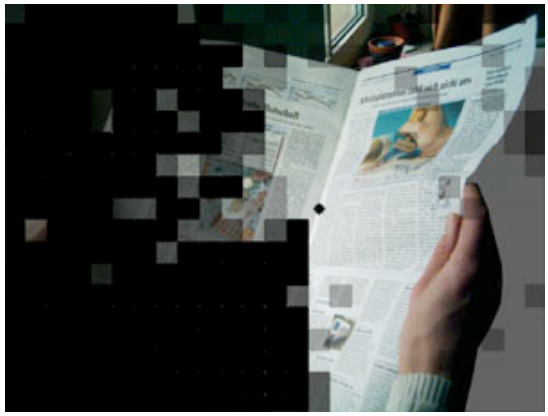


Figure 1.1, upper depiction: Different kinds of anopias, affected by different lesions: white identifies the intact ('sighted') and black the defect ('blind') visual field.
1. Left homonymous hemianopia: incomplete, incongruous, with macular splitting; 2. Bitemporal hemianopia: heteronymous; 3. Right homonymous hemianopia (with macular sparing); 4. Compound hemianopia: total left eye blindness plus right superior temporal quadrantanopia; 5. Central scotoma: homonymous, congruous; 6. Left altitudinal hemianopia; 7. Quadrantanopia, homonymous right superior temporal, congruous; 8. Binasal hemianopia: heteronymous (reproduced from Pietsch, P.).
lower depiction: Vision of a patient with hemianopia and a macular sparing (left reproduced from: Arizona Center for the Blind and Visually Impaired (ACBVI); right reproduced from: Nova Vision. Zentrum für Sehtherapie).

In general, the dimension of a scotoma can decrease from the edges to the centre and in some cases that blind field can omit the centre of the visual field; this phenomenon is referred to as macular sparing[2].

## Residual visual capacities

Originally lesions to V1 were thought to cause irreversible and total blindness in the affected parts of the visual field. However, in 1905 Bard reported that cortically blind patients are able to locate a source of light (Bard, 1905, described in Stoerig, 1999 and Weiskrantz, 2004) and in 1917 Riddoch published a paper, in which he described his examinations of a soldier who had suffered a gunshot wound, resulting in lesions to V1 (Fissura calcarina[3]) and thus to blindness in the affected parts of the visual field. Riddoch found that his patient was able to detect motion (moving stimuli) within the hemianopic field and was conscious[4] of what had been seen.

[2] Macula lutea (Macular) is the area around the fovea. The macular is of size 2.5 mm. and has the greatest concentration of cones 5:2. Macular sparing is discussed in the literature. It is controversial, whether macular sparing in hemianopia really exists or if it is mimicked by unstable fixation during conventional perimetry, when fixation control is insufficient. 'Macular sparing exists and can be determined exactly. Its occurrence depends on the site of the lesion. Its size is of significance for fixation behaviour, the reliability of conventional perimetric results and reading performance' (Trauzettel-Klosinski & Reinhard, 1999, p. 1). Also: 'We believe that macular sparing could be interpreted as a perimetric (not an anatomic) artefact, provided that the results of these tests on 15 patients are confirmed by further similar studies' (Bischhoff, Lang & Huber, 1995, p. 1).

[3] The calcarine fissure (or calcarine sulcus) is an anatomical landmark located at the very caudal end of the medial surface of the brain, beginning near occipital pole.

[4] Consciousness is a quality of the mind generally regarded to comprise qualities such as self-awareness, sentience, sapience, and the ability to perceive the relationship between oneself and one's environment. It is a topic of much research in philosophy of mind, psychology, neurology, and cognitive science. Some philosophers divide consciousness into phenomenal consciousness, which is experience itself, and access consciousness, which is the processing of the things in experience.

Thus Riddoch wrote that his patients '…were immediately conscious of 'something' moving when the object was oscillated' (Riddoch, 1917, described in Zeki & ffytche, 1998, p. 26). This phenomenon (a stimulus perceived during movement but not with static presentation) is referred to as the 'Riddoch phenomena' or statokinetic dissociation. Humphreys (1974) summarized his findings about the rhesus macaque Helen, who had suffered of a quasi-complete bilateral destruction of V1 (the striate cortex was totally removed; on the left-hand side a small island of striate cortex was left apparently intact in the depths of the calcarine fissure), leading to an almost complete blindness. Helen who was studied intensively over eight years regaining an effective, though limited, degree of visually guided behaviour. She could, for example, grasp small moving objects after training and within a few weeks she also showed an ability to detect stationary objects which spread to the whole field. Within a year she could reach immediately towards a stationary black dot in any part of the field that it was presented. Her ability to detect small objects and classify them according to their relative salience suggests that she possessed an almost unimpaired capacity to differentiate visual 'figures' from their background[5].

Comparing animal with clinical findings Weiskrantz (described in Weiskrantz, 1980) examined patient DB. DB had suffered migraine attacks since the age of 14 and at the age of 33 underwent surgery to remove the entire right primary cortex (V1) in order to reduce migraine attacks. After surgery DB, had a corresponding postgeniculate left hemianopia (without macular sparing), with a small amblyopic area of intact vision in the upper quadrant of the visual field.

[5] Colour per se she could not discriminate (as discriminating a 15mm red circle from a 15 mm green circle on a white background). By varying the brightness there was a point where Helens discrimination collapsed completely

In 1976, spontaneous remission resulted in the amblyopic area enlarging. When presenting DB with simple patterns (e.g. horizontal, vertical, diagonal stimuli or sub-components with different orientations as for example in X vs. O) in his blind left visual field, his accuracy was remarkably good. Moreover and besides this impressive visual performance DB denied any kind of awareness of the presented stimuli.

Apparently some visual information seemed to be processed without him becoming aware[6] of it[7]. However, even when patients were not aware of stimuli, they are able to respond if necessary by guessing using forced-choice methods. In contrast to typical forced-choice methods, which refer to telling patients when to give an answer in the form of choosing one of a limited set of presented alternatives (in contrast to letting them freely describe if and when they see something), forced-choice here refers to the introduction of temporal cueing or in other words the demand of responses at a particular moment[8].

[6] Awareness referred to as the ability to dispose of mental states i.e. cognition, emotions, thoughts, perception and memory. Awareness describes a human or animal's perception and cognitive reaction to a condition or event. Awareness does not necessarily imply understanding, just an ability to be conscious of, feel or perceive. The phenomenon of awareness is an unsolved problem of philosophy and natural science. A general accepted precise definition of awareness does not exist.

[7] The visual capacity in a field defect in the absence of acknowledged awareness refers to as blindsight phenomena (e.g. Sanders, Warrington, Marshall & Weiskrantz, 1974 and Weiskrantz, 1986).

[8] This is not necessary for 'super-blindsighters'. Super-blindsighters are trained to respond without being cued, i.e. without being told to guess (to guess when to guess). Humphrey (1970, 1974, described in Stoerig & Cowey, 1997) showed that Helen could discriminate between several targets that differed only in shape, but Helen had to be taught to use her remaining visual abilities and therefore being defined as super-blindsighted as whom in a sense sees everything but recognizes nothing.

Summarized, studies in animals and humans reveal that the idea that lesions to V1 cause irreversible and total blindness in the affected part of the visual field can be rejected. Residual visual capacities have been shown to be at least partially intact during light detection and localisation, movement perception and the discrimination of differently oriented lines (e.g. Weiskrantz, Warrington, Sanders & Marshall, 1974 and Weiskrantz, 1986). Other findings, for example Perenin, Ruel & Hécaen (1980), proved to be in line with Weiskrantz' work on residual visual capacities in the context of unilateral occipital lesions: they found similar residual visual capacities in a case of apparently complete cortical blindness following lesions to both occipital lobes. The ability to locate flickering spots and detect moving visual stimuli was observed.

## Anatomy of visual system and blindsight

Different populations of ganglion cells[9], in the retina send information to the brain from both eyes and via the optic nerve. The optic nerve crosses the midline at the optic chiasm, joining information from 50% of the left and right eyes (nasal and temporal) in the optic tract. In general, the cerebral correlate of human visual function falls broadly into two subsystems, the geniculostriate pathway on the one hand (first visual system) and the extrageniculostriate pathway on the other (tektopulvinar system; second visual system; for all information see e.g. Goldstein, 1997 and Pinel, 1997).

[9] Based on their projections and functions, there are at least five main classes of retinal ganglion cells: midget (parvocellular, or [P] pathway), parasol (magnocellular, or [M] pathway), bistratified (koniocellular or K pathway) and other ganglion cells projecting to the LGN for eye movements as well as photosensitive ganglion cells.

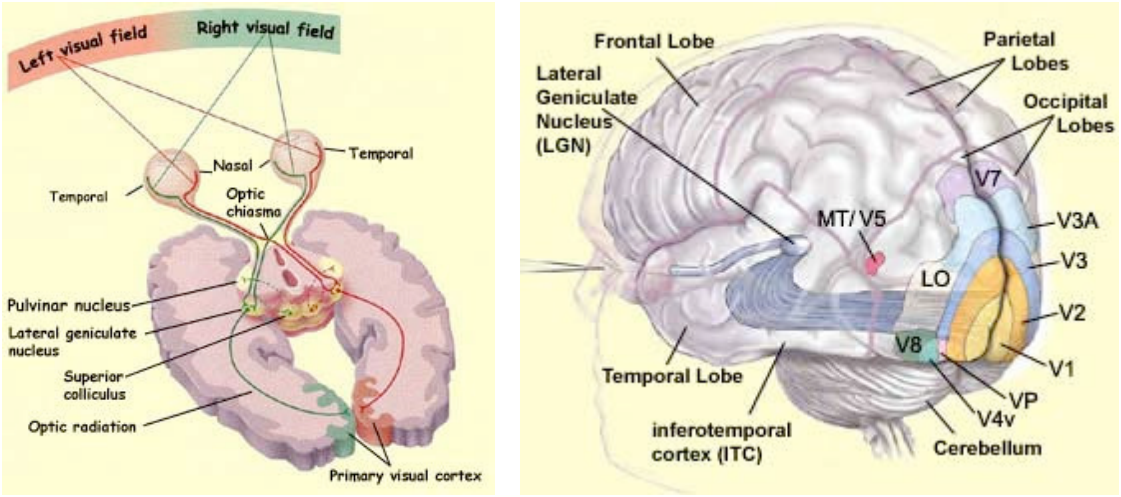



Figure 1.2, left depiction: Visual pathway from the retina to the primary visual cortex (striate cortex, V1; reproduced from Gazzaniga, Ivry & Mangun, 2002).
right depiction: View on the pole of the occipital lobe (both hemisphere) and its topological classification with striate (V1) and extrastriate cortices (V2, V3, V4 and V5/MT; reproduced from Gazzaniga, Ivry & Mangun, 2002).

## First visual system, geniculostriate pathway

Approximately 80 - 90 % of the retinal ganglion cells project to the lateral geniculate nucleus (LGN[10]), a sensory relay nucleus in the thalamus. The geniculostriate pathway is separated into two independent subsystems:

The parvocellular (P) pathway (axons of parvocellular cells [p-cells], with smaller cell bodies) projects to the parvo-layer of LGN (layers 3, 4, 5 and 6). Parvocellular cells are sensitive to colour and need a long time to process information, but do so with high spatial resolution and with lots of information about details.

[10] The lateral geniculate nucleus (LGN, located in the dorsal part of the thalamus [dLGN]) consists of six layers (in humans and other primates): Layers 1, 4, and 6 correspond to information from the contralateral (opposite) eye and Layers 2, 3, and 5 and are connected to the ipsilateral (same) side.

The magnocellular (M) pathway (axons of magnocellular cells [m-cells], with large cell bodies) projects to the magno-layer of LGN (l layer 1 and 2, ventrally located and thus next to the incoming optic tract fibers). Magnocellular cells are achromatic (need a short time to process information, without much spatial detail) and are sensitive to motion and depth. The majority of magnocellular cells are highly sensitive to contrast.

The (P) pathway is more sensitive to medium and high spatial frequencies while its temporal resolution is rather moderate. Responses generated by this subsystem are persistent in that they may extend over a period of time and may be distinguished from the responses of the (M) pathway which is responsive to low spatial frequencies, provides a high temporal frequency resolution and generates transient responses.

Previously p-and m-fibers ([P] and [M]-pathway) were thought to dominate the ventral and dorsal streams, respectively, but more recently these projections are thought to be a mixture of different types of fibers[11]. Note that in between p- and m- layers lies a zone of very small cells that receive information from the k- (koniocellular) cells in the retina.

[11] Excursion: V1 transmits information via two pathways, referred to as the ventral and the dorsal stream (Ungerleider & Mishkin, 1982; also: 'what (ventral) /where or how (dorsal)' or 'action/perception' streams): The ventral stream (temporal pathway) begins with V1, the simplest and earliest cortical visual area. It is specialized for processing information about static and moving objects and is associated with form recognition and object representation as well as with storage of long-term memory. The V1 is divided into six functionally distinct layers (1-6). Layer 4, which receives most visual input from the lateral geniculate nucleus (LGN), is further divided into 4A, 4B, 4Cα, and 4Cβ. Sublamina 4Cα receives most magnocellular input from the LGN, while layer 4Cβ receives input from parvocellular pathways. The ventral stream goes through V2 (BA 18), which is the first region within extrastriate cortex to V4 projecting to the inferotemporal cortex (IT, temporal lobe, TE). The dorsal stream (parietal patheway) begins with V1, goes through visual area V2, then to V3 (BA 19), which projects to V5 (hMT+, mediotemporale cortex); a region in the extrastriate cortex that appears to process complex visual motion. The dorsal stream terminates in the parietal lobe (PG); it's associated with motion, representation of object locations and control of the eyes/arms (i.e. saccades or reaching). Previously m-fibers were thought to dominate the dorsal streams and p-fibers were thought to dominant the ventral stream. However, new evidence has accumulated showing that the two streams appear to feed on a more even mixture of different types of nerve fibers.

These cells are functionally different from p-and m-cells and their role is not clear. Finally most of the cells of the LGN project to V1 and further to extrastriate areas such as V2, V3, V4 and V5/MT. Note, that there even seems to be some direct linkages of parvocellular cells to extrastriate layers relayed by the LGN (for all information see e.g. Goldstein, 1997 and Pinel, 1997).

First visual system and blindsight

Lesions in V1 cause a descending degeneration, which leads to the decimation of projecting neurons of the LGN with further effects upon retinal ganglion cells (after long periods of time neurons in the affected regions of the retina can be reduced in number by up to 80%, see Stoerig, 2003). Taking anatomical considerations suggests there may be a number of means of mediating residual visual capacity. In relation to the geniculostriate pathway, which, besides projecting directly to extrastriate cortices, also projects to V1, residual vision, may be due to a) neuronal plasticity in surrounding (retinal or cortical) regions of the scotomata, or areas of the contralateral hemisphere which could assume some functionality in the field defect by reorganisation of their neuronal receptive fields b) surviving fibres in the optic radiation and other structures or c) activity in V1 within islands of undamaged tissue that respond to sufficient visual information, through micromovements of the eyes, thus providing some basis for detection, discrimination or localization. Thus residual vision may be due to some surviving activity in V1 and therefore would only differ quantitatively not qualitatively from normal visual capacity. In the case of visual capacity in the absence of awareness,

for example blindsight, one could argue that residual visual function is simply too weak to lead to awareness, but might also be mediated by residual activity in V1.

Fendrich, Wessinger and Gazzaniga (1992), examined the role of the geniculostriate pathway in blindsight, found a 1° island of vision well away from the region of macular sparing in the blindsight patient GY (who had a right hemianopia, with 3° of small macular sparing, based on a postgeniculate damage of the medial occipital lobe of the left hemisphere, destroying V1, surrounding extrastriate visual cortex, and the underlying white matter, but sparing the occipital pole, as a result of a head injury from a road accident when he was eight years old; e.g. Stoerig & Cowey 1997 and Weiskrantz, 1996).

This is in contrast to examinations of extrastriate activation, undertaken by Stoerig, Kleinschmidt and Frahm (1998), who examined blindsight patient FS (who had a right homonymous incomplete hemianopia, without obvious considerable macular sparing. This is in accordance with the damage of the left hemisphere, caused as a result of a head injury form a road accident [which lead to a severe craniocerebral trauma], when he was at the age of 42; Kleiser, Wittsack, Niedeggen, Goebel & Stoerig, 2001 and Stoerig et al., 1998; for details see Appendix, p. 153.)

They used functional Magnetic Resonance Imaging (fMRI) and a large flickering stimulus field to assess visual responsiveness of deafferented V1. They found an activation in extrastriate cortex, concluding '…that blindsight does not depend on functional islands of tissue preserved within the deafferented striate cortex.' (Stoerig et al., 1998, p. 21) Additionally by examining patient GY, using MRI and Positron-Emissions-Tomography (PET), Weiskrantz (1996) found no activity in V1 at all, including an absence of isolated intact islands, but activity in V5 and elsewhere when

presenting moving stimuli in GY's defect field. Further examinations of FS and GY using fMRI (Stoerig & Cowey, 1997) have found activation in extrastriate cortices in both patients in close agreement with the physiological results obtained in monkeys. According to Stoerig (2003), examination of e.g. GY and FS have revealed that visual responses to moving stimuli were, in general, independent of activity in V1 and are mostly found in occipito-parietal cortex (V3 and hMT+[12]), and in the occipital-temporal cortex when

presenting coloured pictures of 'natural' objects instead of moving stimuli (e.g. Barbur, Watson, Frackwiak & Zeki, 1993 and Goebel, Muckli, Zanella, Singer & Stoerig, 2001, described in Stoerig, 2003). Note that Weiskrantz (1980) points to a qualitative difference between the two phenomena of residual capacities in blind fields and intact visual areas, by comparing measures of detection and form discrimination in the intact and blind field of patient DB. What he found was a double dissociation concerning signal detection and form discrimination. Form discrimination capacity was better in the intact field as one would expect. However in contrast, signal detection (sensitivity for a spot detection task) capability was found to be better in the blind area. The author assumes this dissociation to be due to different criteria adopted in the intact and blind field.

In conclusion the anatomy suggests there may be a number of means of mediating blindsight in spite of V1 being partly or totally destroyed.

[12] hMT+ or V5 is located in the dorsal pathway of the primate brain, specialized in the processing of visual motion information.

Second visual system, the extrageniculostriate pathway

The second visual system, or extrageniculostriate system, consists of residual axons projecting from retina to the suprachiasmatic nucleus [NSC] in the hypothalamus, the superior colliculus (SC[13], a part of the tectum in the mesencephalon [midbrain]), prectectum[14] and pulvinar[15] nucleus to extrastriate cortices.

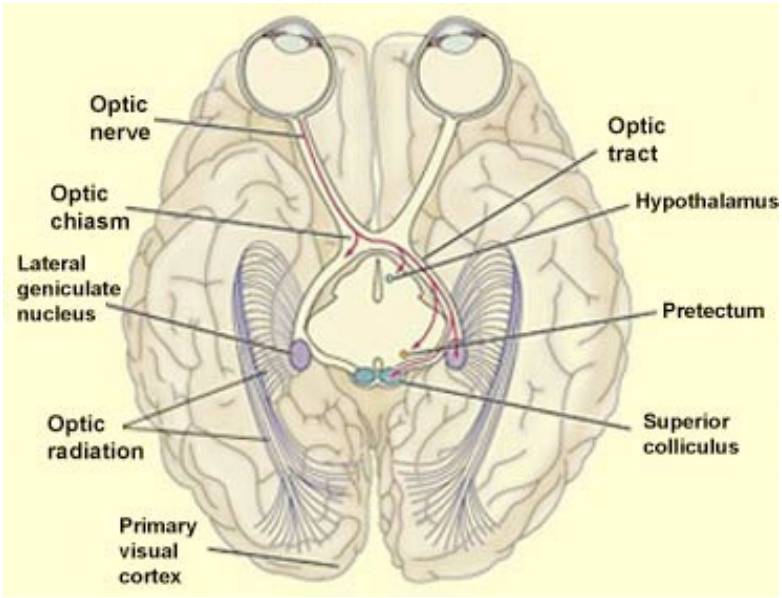



Figure 1.3: Geniculostriate and extrageniculostriate pathway from the retina to the primary visual cortex (striate cortex, V1; reproduced from Gazzaniga, Ivry & Mangun, 2002).

[13] SC and the inferior colliculus are located on the posterior surface of the Tectum. Both are known together as the corpora quadrigemina. The inferior colliculus is involved in auditory processing. The SC is involved in preliminary visual processing as detection and localization of objects, motion and the resolution of saccades (eye movements and eye head coordination). Afferents to the SC originate in the cerebral cortex, inferior colliculus, retina, basal ganglia, and spinal cord. Efferents project to the pons, spinal cord, and elsewhere (e.g. Goldstein and Pinel).

[14] Pretectum is innervated by SC, the pulvinar nucleus, the frontal eye fields and visual cortex.

[15] The Pulvinar is usually grouped as one of the lateral thalamic nuclei, which has widespread connections with extrastriate cortices.

In an evolutionary sense this system is the phylogenetically 'older system' (for all information see e.g. Goldstein, 1997 and Pinel, 1997).

The second visual system and blindsight

Weiskrantz (1997, described in von Wartburg, 2001) assumed that the 'older system' takes responsibility for visual processing when the 'new system' is lost. This assumption is related to the ideas that the extrageniculate pathway to extrastriate cortex, relayed by SC, the pulvinar or other nuclei leads to residual vision (e.g. Perenin, Ruel & Hecaen, 1980). For the most part, residual visual capacity is believed to result from activity in the most important projection from retina ganglion cell axons to the SC, a part of the tectum. This is believed in part because SC and V1 exhibit a similar retinopic representation of the visual field. Cells, in these structures have receptive fields with antagonistic on- and off areas, although with no apparent functional specialisation. Note as the extrageniculostriate system, consists of residual retinal ganglion cell axons (e.g. magnocellular cells) and that the (M) pathway is responsive to low spatial frequencies, provides a high temporal frequency resolution and generates transient responses.

Mohler and Wurtz (1977) conclude that the SC is directly implicated in residual visual capacity, as they have found that monkeys with a small part of striate cortex removed could still direct their eyes to a spot of light presented in their visual defect. If the corresponding part of the SC was removed, this ability was lost.

Another important connection is the one from the retina to NSC in the hypothalamus. This is located deep in the medial temporal lobe and is responsible for maintaining circadian rhythm. One interesting point is the close location of NSC to the

optic nerve: If the optic nerve is severed before the NSC, the NSC will not be influenced by light-dark-impulse (and will not signal light dark changes). However if the optic nerve is cut through after the NSC, there is no influence on the light-dark-changes. One more interesting point is that SC projects to cell clusters in the thalamus such as the pulvinar nucleus (which has further projections from the retina and the pretectum and which have widespread connections with extrastriate cortices) and further to amygdala. For example GY was found out to be able to discriminate different emotional facial expressions presented in the blind field (deGelder, Vroomen, Pourtois & Weiskrantz 1999, described in Morris, DeGelder, Weiskrantz & Dolan, 2001). Using fMRI Morris et al. found an increase response in bilateral regions of the amygdala when presented GY 'fearful faces' in the defect field, in comparison to 'happy faces'. Morris et al. concluded that there are connections between thalamic neurons and the amygdala and that the '…amygdala forms part of a secondary extrageniculostriate visual system' thus a '…phylogenetically ancient fear system can function independently of the more recently evolved geniculostriate visual system and without normal visual awareness' (Morris, Ohman & Dolan, 1999a, described in Morris et al., 2001, p. 1251).

## Typology of residual visual capacity

Besides the different roles of the anatomical structures involved in residual vision, it is necessary to discriminate between different forms of residual visual capacity; specifically a differentiation may be made between residual visual capacity accompanied by some kind of awareness, and visual capacity occurring without any awareness.

Visual capacity without awareness can be described as the ability to detect or discriminate stimuli, but without direct conscious experience of the stimuli. Based upon this dissociation between visual capability and awareness, Weiskrantz (e.g. Sanders, Warrington, Marshall & Weiskrantz, 1974 and Weiskrantz, 1986) coined the term blindsight to refer to visual capacity in a field defect in the absence of acknowledged awareness. In contrast to blindsight, residual vision is the ability to perceive phenomenological or experientially some kind of visual stimulus within a defect field in a weakened fashion but nonetheless with awareness.

In this relation it should also be mentioned that there are occasions on which patients, showing blindsight, who are actually capable of some accurate performance but only when mediated by unconscious processing of visual information, become aware of visual events if those events are sufficiently salient. Patients themselves do not describe their phenomenal impression as ‘seeing’ but rather as a kind of ‘feeling’ that something appeared or has moved within their blind field. For example, in spite of DB’s overall good performance in blindsight detection tasks he denied any conscious visual impressions and assured the experimenter that he was just ‘guessing’. Alternatively he reported ‘knowing’ about a stimulus or having a ‘feeling’ of a stimulus, which is e.g. ‘smooth’ in case of the letter ‘O’ or ‘jagged’ in case of the letter ‘X’, but without

'seeing' (Weiskrantz, Warrington, Sanders, & Marshall, 1974 and Weiskrantz, 1986). Weiskrantz (1986) also reports an impressive dialogue he had with DB in blindsight:

> 'Did you know how well you have done?', he was asked. 'No,' he replied, 'I didn't – because I couldn't see anything; I couldn't see a darn thing.' 'Can you say how you guessed – what it was that allowed you to say whether it was vertical or horizontal?' – 'No, I could not because I did not see anything; I just don't know'.

As DB, GY was able 'to respond to a moving target and to mimic its path along different straight and curved trajectories with his hand, throughout the whole of his blind hemifield' additionally GY reported that 'he did not actually 'see' or 'sense' anything, but 'knew' that there was movement and its direction' (Weiskrantz, 1996, p. 216). GY '…insists that the use of visual terms is for lack of a better alternative because in fact he does not see the stimulus', thus he tries '…to find an appropriate description, but then again finds that 'it's impossible, like trying to explain seeing to a blind person' (personal communication with Stoerig and Cowey, Stoerig & Cowey, 1997, p. 554-555). Additionally GY was able to exhibit normal responses to spectral aspects of the stimuli and could verbally identify colour stimuli presented to the blind hemifield, although such colour naming was achieved without the conscious perception of any colour (Brent, Kennard & Ruddock, 1994, described in Weiskrantz, 1996).

Concerning conscious and unconscious perception Marcel (1998) examined patient TP, (who had a complete right homonymous hemianopia based on surgery of unilateral left occipital cortex following a cerebral haemorrhage, when she was 50 years of age) and GY. The paradigms employed in this examination used indirect measures

(priming)[16] and illusory figures which spanned both intact and blind fields. The illusory contours were Kanizsa-type figures[17] which were positioned within the blind and the intact hemifields. The patients showed conscious perception of the illusory contours in the blind field. In another experiment Marcel could show conscious perception by investigating after images of shapes presented in the intact and another in the blind fields, the elements of which together formed a good Gestalt (e.g. shape, form). These results demonstrate that aspects of shape are much better perceived within blind fields than previously thought. Marcel concluded '…that the main deficit in blindsight is one of consciousness…', but not a total loss of consciousness in the blind field (Marcel, 1998, p. 121).[18] This lack of a total loss of consciousness was proposed due to patient GY who is sometimes able to discriminate moving stimuli without showing a total loss of consciousness (in terms of being able to give commentaries to his response).

One might ask of the differences to Riddoch's syndrome, as it is a similar capability to perceive moving stimuli with being aware of them. One can argue, that patient GY denied to be aware of the stimuli and that he is not only able to discriminate moving stimuli, but also process aspects of the stimulus such as orientation which is additionally not always accompanied by an explicit awareness of the stimulus orientation.

[16] Note that Marcel also could show '…that indirect techniques (priming) are more sensitive to showing effects of non-conscious perception than direct ones (forced-choice)' (Marcel, 1998, p. 121).

[17] An illusory figure made of a collinearity grouping of single elements with corner junctions.

[18] Besides Marcel, Gregory, 1972 (described in Weiskrantz, 1980), confirmed the spatial localisation capacity and could show remarkable interactions between parts of the visual fields in the intact and blind fields using the Kanizsa triangles.

In an experiment with patient GY examining both unconscious discrimination and conscious visual awareness of moving stimuli Weiskrantz, Barbur and Sahraie (1995) found that GY showed an excellent capacity to discriminate motion direction and orientation in the absence of awareness and that discrimination with awareness apparently follows a different functional relationship with respect to stimulus speed, displacement, and stimulus contrast.

Concerning anatomically distinguish in blindsight findings suggest that an activity in V1 can be excluded as a likely source of visual capability with blindsight based on activity in extrastriate cortex (Weiskrantz, 1996; Stoerig & Cowey, 1997; Stoerig et al., 1998; Stoerig, 2003) and is mediated by the extrageniculate pathway (Mohler & Wurtz, 1977; Perenin, Ruel & Hecaen, 1980; Morris et al., 2001). Concerning visual awareness blindsight can be accompanied by a total loss and sometimes by a loss of consciousness but not a total loss. In this respect one might discuss awareness and its neuronal correlation. Crick and Koch (1995a and 1995b) assumed an exclusion of activity in V1 in consciousness (although activity in V1 may be necessary for vivid and veridical visual consciousness [as activity in the retina], but the firing of none of the neurons in V1 directly correlates with what we consciously see). Rather it seems that awareness is related to activation of the higher-systems as extrastriate (e.g. V5) or prefrontal cortices (Koch, 1994). This suggestion can be supported by findings of Zeki and ffytche (1998), who tested GY using fMRI and using moving stimuli (which he had to discriminate) '…of which he was consciously aware, without distinguishing between feeling or seeing, and stimuli which he could discriminate without any sensation or feeling or experience of the visual event' (Weiskrantz, Barbur & Sahraie, 1995, described in Zeki & ffytche, 1998, p. 39). What they found was activation in V5 when he had

consciousness experience and they concluded that consciousness experience is possible without V1. Additionally in a further fMRI study, Sahraie, Weiskrantz, Barbur, Simmons, Williams and Brammer, (1997) examined the neuronal correlates of the conscious and unconscious 'blindsight modes' in patient GY. They found an activation of extrastriate and dorsolateral prefrontal cortices (area 46) in the 'conscious mode'[19]; while in the 'unconscious mode' subcortical structures (SC together with medial and orbital prefrontal cortical sites) were active.

Based on these findings it can be assumed that consciousness in blindsight is related to activation in extrastriate cortices whereas unconscious, blindsight performance relates more to activity in the extrageniculate pathway.

In detail and concerning unconsciousness in blindsight Stoerig and Cowey (1997) described four possible levels of visual capacity: At the lowest level neuroendocrine reactions can be found, such as the suppression of melatonin as a reaction to light (via the NSC and hypothalamus) and absorption by remaining functional light-sensitive retinal cells (sometimes even revealed in retinally blind patients). Secondly there are reflexive reactions as the blink reflex: The pupil continues to respond to changes in illumination, to spatial and at least in patients to spectral information, in the form of the blink reflex and eye movements when presented with moving visual scene.

[19] Both modes were examined by commentaries he gave in earlier studies to rapidly moving targets.

Its subcortical component Optokinetic nystagmus (OKN[20]), whose status is not clear, involves visual reflexes that persist in the absence of functional striate cortex. Furthermore and apart from OKN '... visual reflexes persist in the absence of functional striate cortex, although they may be sub-normal, with the papillary constriction to light being of lesser amplitude' (Stoerig & Cowey, 1997, p. 536). There are processes at higher levels, such as the implicit processing of visual stimuli which prime task performance. A stimulus presented within a defect field, without requiring the observer to respond to it directly would be examined in terms of its effect on a response to a seen stimulus in the normal visual field. If this response is altered in some way by the unseen stimulus, information from the blind field must have been processed implicitly. There are different test arrangements: simultaneous or prior presentation of an unseen stimulus can significantly alter the mean reaction time (RT) to a seen stimulus. Another arrangement and effect is that of a more complete appearance when half of a full circle falls into the blind field (i.e. hemianopic area), than when half of a circle falls entirely into the intact field. Stoerig and Cowey (1997), for example, have shown that an enhancement of the phi-effect (i.e. the perception of motion through the successive presentation of two stimuli at closely adjacent locations) could be achieved by adding one additional stimulus in the blind field. Another form of visual capacity is the directionally specific reactions to stimuli presented in the blind field.

[20] OKN is a reflexive periodic eye movement which helps to hold the image of a moving target on the fovea. In human OKN is controlled not only by the brainstem but also by cortical structures and it's influenced by orientation, attention, and fatigue. One assumption is that human OKN appears predominantly in relaxed state. Indeed 'Alpha synchronisation correlates with the augmentation of OKN, and alpha desynchronization correlates with the exhaustion of OKN' (Gulyas, Palvolgyi & Szirmai, 2004). Nystagmus is an involuntary trembling of the eyes. The optokinetic nystagmus is a physiological nystagmus (to be distinguished from pathological). It occurs when one tries to fixate an object moving through the visual field. In this case the nystagmus movements can be horizontal, vertical or rotating.

This level reflects the 'classic' (or forced-choice) paradigm and was revealed in the first experiments of Weiskrantz. Patients are able to localize by hand or eye-movement the approximate position of a stimulus. Thus can detect stationary and moving stimuli interleaved randomly with blank trials, can discriminate stimulus orientation, target displacement, direction of motion and wavelength. In conclusion, only the last two processes can be included in the concept of blindsight without awareness as they are usually conscious in normal vision.

However, in conclusion and in view of the differentiation detection performance (on-line processing) and patients state of awareness of visual events (off-line processing; Weiskrantz, 1997, described in Trevethan & Sahraie, 2003), Trevethan and Sahraie (2003) distinction between blindsight I, i.e. discrimination performance without any kind of acknowledged awareness, and blindsight II, discrimination performance in the presence of awareness without 'seeing' per se (or denying any experience of 'seeing') is adopted.

## Training of the transition zone

The performance of trained humans performing detection tasks and using information just inside the edge of their field defect (i.e. the border of intact fields, relative blinds and absolute blind fields, which is referred to as the transition zone) has lead to some good indications that the morphology of the visual field defect can constrict with training. Related to the idea that a lesion in the central visual system does not always result in a complete and permanent loss of function Zihl and von Cramon

(1979) trained patients with postchiasmatic lesions on light- difference thresholds, which were determined repeatedly in the transition zone. They found that by systematic visual stimulation in the transition zone an improvement in contrast sensitivity and an increase in size of the visual field could be obtained[21]. Zihl and von Cramon (1985) examined a group of 55 homonymous patients (with vascular or traumatic post-geniculate lesions) who were trained by locating light targets presented within their blind field region. They discovered that the majority experienced an enlargement of the visual field. This recovery is assumed to result from reactivation of reversibly damaged nervous tissue, while patients without benefit training induced might be concluded to have irreversible damage. In contrast to Weiskrantz, Sabel (2005) has argued that rehabilitation of visual field functionality does not depend on the age of patients and/or age of lesions. Instead, training is possible due to neuronal plasticity, which is a general phenomenon and is also apparent in visual field enlargement during spontaneous recovery as well as following specific visual training.

According to Horton (2005) in sensational series of reports, Sabel and colleagues (for original report about VRT see Kasten & Sabel, 1995, described in Wüst, Kasten & Sabel, 2004) described recovery of homonymous visual field defects following intensive computer-based vision restoration therapy (VRT) for the treatment of partial blindness through stimulating the transition zone. VRT requires a training duration of 6 months and of at least 150 hours (1000 trials and one hour a day) training. Patients practise perimetry at home for an hour a day, six days a week, for the six months period using a software program (NovaVision by Sabel) loaded on their personal computer. The monitor is recommended to be set at a distance of 30 cm from

[21] No spontaneous recovery was observed between or after the periods of training.

the patient while the stimuli are white, suprathreshold lights measuring 0.15° in diameter shown against a dark background. Using these techniques, Kasten, Poggel, Muller-Oehring, Gothe, Schulte and Sabel (1999) have reported that transition zones can shift for up to about 5° of visual angle and that more than ¾ of conducted patients reported subjective improvements in visual performance. Kasten, Wüst, Behrens-Baumann and Sabel (1998) refined previous reports in showing that for optic nerve patients the effect of improvement over baseline in the ability to detect visual stimuli were even more pronounced than for patients with post-chiasmatic brain injury. Patients receiving placebo training did not show comparable improvements. Kasten, Poggel and Sabel (2000) also examined the extent of transfer of the VRT training effects to other visual dimensions and concluded that training using a simple white light stimulus has at least some influence on improving discrimination of colours and patterns.

In contrast to the studies reviewed above, Reinhard, Schreiber, Schiefer, Kasten, Sabel, Kenkel, Vonthein and Trauzettel-Klosinsiki (2005) have provided evidence suggesting VRT to be a relatively crude measure or means for potential visual field restoration. They examined 17 patients with stable homonymous field defects, to determine whether or not VRT is able to change absolute homonymous field defects. Patients' visual fields were assessed with fundus controlled microperimetry (using a scanning laser ophthalmoscope [SLO]) before and after treatment to assess the outcome of VRT therapy. The results showed no significant homonymous changes of the transition zone, even after six months of training and in spite of most patients reporting a subjective impression of benefit from the therapy. Horton (2005), has argued that several aspects of the VRT therapy require consideration: firstly, the proposed mechanism for partial field recovery in patients with complete hemianopia is flawed:

'In such subjects the normal occipital lobe and the affected occipital lobe are physically separate – no fringe of injured but salvageable tissue exists that represents the border of the visual field defect.' Horton goes on to state that training programmes reported to be effective for both monocular optic nerve diseases and homonymous, post-chiasmatic lesions are questionable, as there is no '…physiological mechanism that could explain improvement from the same treatments at different levels of the visual system' (Horton, 2005, p. 1). Additionally, there is no evidence that the visual cortex of an adult is trainable in contrast to, for example, the learning of new motor skills (achieved by patients with partial paralysis by e.g. a stroke). This latter possibility arises due to still functional muscle groups and cannot be considered equivalent to or comparable with the action of surviving neurons.

At the end the question should be raised of why an artificial stimulus applied for one hour a day is more effective than the rich repertoire of natural light patterns that stimulated brain under normal, everyday circumstances? Horton assumes that successful training is in reality just due to procedural artefacts such as an inability of maintain fixation and to keep the training stimuli in the blind field. In support of this point of view, Horton refers to Balliet, Blood and Bach-y-Rita (1985), who examined twelve patients (homonymous hemianopic or quadrantanopic) with similar methods, but in which possible contaminating experimental variables were controlled for. In their study the morphology of the visual field did not change.

## Temporal dynamics

### Perceptual organisation and synchronization

Although our representation of the world constitutes an ambient array of multiple sensory experiences, our perceptual system is able to discriminate within the complex visual environment different objects and specify the parts and properties of these objects. For this performance the perceptual system must not only be able to specify these parts and properties of objects, but also be able to combine them to a coherent representation of objects, as separate from their backgrounds. This process is known to involve the extraction of primary dimensions such as form, color or movement by specific and physically separable anatomical structures (Hubel & Wiesel, 1962 and Zeki, 1993). The features of a complex visual scene are believed to be processed separately in cortical areas, which map a given feature to a given location in visual space (Treisman, 1988). Since it is known that complex visual information elicits a number of responses in spatially distributed neuronal networks (i.e. the ventral and dorsal visual pathways (Ungerleider & Mishkin, 1982) the question arises of how this distributed information can be recombined or 'bound' into the representation of a coherent object-based representation. This problem of integration is usually referred to as the 'binding problem' and has been the topic of active research for over 20 years.

There have been several approaches to solve the binding problem. One classical proposal states that there are specialized areas in the brain where all distributed activities converge onto neurons that respond in highly selective manner only to specific constellations of primary features. This 'single cell doctrine' faces several problems based on the implication that single cells would be required for each and every object

and for each novel perspective of each object (Singer, 1993). The large number of cells needed to code all the information in the environment would result in a 'combinatorial explosion' (Singer & Gray, 1995), requiring far beyond the number of cells available in visual processing areas. The Hebbian model (Hebb, 1949) proposes an interconnection of simultaneously activated neurons corresponding to features of a certain object. In this model one single neuron can be part of more than one such assembly, allowing visual complexity such as the motion of an object or different perspectives of the same object to be in principle managed by the perceptual system in such a way that the object's identity is preserved across changes. A suggestion is that all cells participating in a given assembly could be labeled so they can be recognized as being related irrespective to variations in the environment. This concept of 'assembly coding' has the essential advantage that individual cells can participate at different times in the representation of different objects, making information processing highly effective without the need of a large amount of specific information processors as it would be necessary in the 'single neuron doctrine' (Singer, 1993). As a consequence, single cells would be able to participate at different times in the representation of different objects. A disadvantage here is that the model only works to explain the perception of one single object at any moment in time. If one object is coded by a certain activated neuronal assembly, all other assemblies have to be suppressed in the meantime otherwise multiple co-active assemblies would lead to a 'superposition catastrophe'. This is because no mechanism exists to differentiate the features coded in one assembly from those coded in another. One solution to this problem is that a process of labeling related neurons of one assembly takes place in the temporal domain by means of the synchronization of neuronal firing activity.

The possibility that neurons are bound into assemblies by a temporal code seems to be an attractive solution to the binding problem (as suggested by von der Malsburg, 1981, 1985 and von der Malsburg & Schneider, 1986; see also the 'temporal correlation hypothesis', e.g. Gray & Singer, 1989). The solution would be achieved because synchronization could lead individual stimulus features of one object to group to form a Gestalt in one phase of a processing rhythm while other features of other objects group in different phases. Thus any number of objects may be simultaneously represented up to the fidelity at which phase differences of neuronal activity at a given frequency are discriminable by target neurons. Physiological studies have shown the synchronous firing of neurons responding to different aspects of the same visual Gestalt which may be a physiological correlate with the 'binding' (i.e. the combination) of visual information. Under Gestalt grouping conditions, neurons responding to elements of the same Gestalt principle (e.g. continuity, vicinity or common motion) coordinate by adjusting their firing pattern so that they oscillate in synchrony especially in the gamma-band range (~ 20 - 80 Hertz [Hz]; e.g. Engel, König, Kreiter & Singer, 1991).

Psychophysical investigations

As is mentioned above, synchronous oscillatory activity is suggested as the neural mechanism underlying perceptual integration with a particular role in the binding of features according to global stimulus properties such as continuity, similarity or orientation. Elliott and Müller (1998) examined if spatially distributed stimulus components may become grouped into coherent wholes only by virtue of alignment of stimulus presentation phase. Their paradigm is based on the assumption that internal

feature coding mechanisms are entrainable by external stimulus modulation and further it was proposed that by systematically varying the frequency of external stimulus events, critical frequencies for (internal) feature-object coding may be established and made available for empirical investigation. Their preliminary results revealed evidence for frequency-specific object priming at 40 Hz leading Elliott and Müller to the conclusion that form-based processing can be influenced by synchronized stimuli presented in stimulus matrices that flicker at the same frequency as neurons synchronize in visual cortex. Elliott and Müller (2000) proposed these effects come about because early and local neural activity might become primed at 40 Hz, whereby this activity is the fed back from later cortical mechanisms. Note that Crick and Koch in 1990 asserted that synchronized 40-Hz oscillations within the subset of neurons that correspond to an attended object is a signature of the neuronal correlation of consciousness (NCC; Crick and Koch 1990a and 1990b, described in Koch, 2004).

Temporal investigation in perceptual deficits

Assumptions that impaired synchrony are likely to account for perceptual deficits comes, for example, from investigations of the effects of strabismic amblyopia[22] in cat (reported in Singer, 1999). The remarkable finding was that neurons in V1 of amblyopic cats responded quite normally to light stimuli. The only abnormality found was a reduction in response synchrony between neurons driven by the amblyopic eye.

[22] Strabismus is a misalignment of the eyes. Strabismic amblyopia is a developmental impairment in vision, which results in reduced visual acuity, suppression of the amblyopic eye and crowding. Crowding is an inability to identify target stimuli if these are surrounded by contours. This is assumed to result from false binding and target-background segmentation processes in perceptual organization.

The impaired synchrony is supposed to count for a decrease in saliency of the visual stimulus and thus represent inferiority in input from the amblyopic eye in contrast to the unimpaired synchronized responses to the input from the normal eye. Furthermore the reduced visual acuity and the phenomenon of crowding can be traced back to impaired neuronal synchronization as it causes poorer segmentation in terms of impaired disambiguation of responses evoked by adjacent stimuli.

Although residual vision in patients with cortical blindness is common, its brain mechanisms are poorly known and studied rarely. Vanni, Raninen, Näsänen, Tanskanen and Hyvärinen (2001) examined the dynamical pattern of cortical activity in MR who had a postgeniculate left visual field hemianopia based upon a lesion covering the right occipital lobe, the nearby extrastriate cortices and the geniculate pathway in the right hemisphere brought about by a stroke when he was about 50 years old. Vanni et al., used magnetoencephalographic (MEG) recordings to compare activation in the healthy side with that in the lesioned side of visual cortex; MEG was recorded while MR viewed different transient stimuli pattern: he was presented either with a checkerboard pattern, which altered contrast repetitively, or luminance-modulated letters that flickered sinusoidally at 10 cycles /sec. MR underwent intensive training before the study for detecting flickering luminance patterns and had achieved detection thresholds in the peripheral parts of the two hemifields. The MEG revealed residual visual capacities to be accompanied by a non-normal distribution of brain activity. In particular Vanni et al. found stimuli in the affected hemifield failed to generate an early fast transient response at the posterior cortical regions and a later and relatively strong response in the contralateral superior temporal (ST) regions. As the strength of MEG responses is dependent upon the size of the active area the authors suggest that the

attenuation of transient occipital responses of the affected hemifield might be due to smaller number of active neurons. However, Vanni et al. concluded that '…the lack of early posterior synchronized neural activation is causally related to the enhanced longer-latency ST activity: compensation of the impaired input by enhanced higher- order processing may be necessary for the residual vision in the affected hemifield.' (Vanni et al., 2001, p. 865).

Recently the presence of temporal sensitivity with particular band-pass characteristics in residual vision and blindsight has been suggested. Teuber, Battersby and Bender (1960; described in Trevethan & Sahraie, 2003) found cortically bind soldiers commented on still being able to discriminate light/dark onsets. However, Weiskrantz (1986) reports better discrimination of rapidly flickering stimuli presented in the blind field of patient DB. Flickering targets are also better localised in space (Perenin, Ruel & Hecaen, 1980, described in Trevethan & Sahraie, 2003). Barbur, Harlow and Weiskrantz (1994) studied temporal processing in patient GY and discovered that for sinusoidal gratings forced-choice detection scores (in this instance measured in terms of percent correct) were substantially greater than 50 % for stimuli presented in the range ~ 6 - 40 Hz. Trevethan and Sahraie (2003) investigated another case of cortical blindness in VN, who had a postgeniculate right lower quadrantanopia with 1° macular sparing, based on left occipital damage resulting from a removed arterovenous malformation. Consistent with previous research, in which they found discrimination of temporally modulated gratings was enhanced in contrast to rapid on/off-set static gratings (Sahraie, Weiskrantz, Trevethan, Cruce & Murray, 2002, described in Trevethan & Sahraie, 2003) Trevethan and Sahraie (2003) also found a narrowly tuned temporal channel mediating blindsight performance: there was an above

chance performance of detecting the presence of a sinusoidal grating occurred when the grating was modulated at a narrow range of frequencies between 10 and 33 Hz (with maximum sensitivity at 20 Hz). A further effect was that the level of awareness was higher under the experimental conditions for investigating temporal properties than in the additionally conducted examinations on spatial properties. They conclude that this as well may be attributed to the temporal content of the stimulus. Schurger, Cowey and Tallon-Baudry (2006) presented stimuli of different orientation with stationary stimuli at fixed near-threshold level of contrast to which patient GY sometimes responded 'aware' and sometimes 'unaware'. The MEG was recorded in this study in order to determine the relationship between local induced gamma-band oscillations and oscillatory activity in the EEG gamma-band (in this case in the range 44 - 66 Hz). What they found was gamma activity in the left occipito-parietal cortex correlating significantly with awareness (but neither with accuracy nor with RT), whereas activity in the alpha-band (8 - 12 Hz) did not. Note that GY's accuracy was significantly better than expected by chance but unaffected by his reported awareness of the stimulus.

## The aim of the study

Based in part on selected evidence elaborated upon above the visual system is regarded as being temporal in its basic characteristics. The architecture of temporal visuo-cortical function is considered to be a distributed dynamic system perceptually organised in a form of equilibrium state. Visuo-cortical dysfunction, attributable to some non-specific cortical lesion – if its dimension does not cause total loss of function – may result in an inability to establish a state of equilibrium. This might happen by

virtue of the alteration in temporal characteristics of the distributed system which results in an inability to synchronize correctly or 'miss-synchronization' with a commensurate elevation of noise to signal in neural circuitry that might otherwise function with some residual capability. With this in mind, in this study it was examined whether direct physical modulation of visual input in terms of conditioning of a frequency response at frequencies believed to be important for visual binding operations, enhances if not even mediates blindsight and residual visual capability (via forced-choice and feedback[23]).

A general enhancement of response accuracy following temporal modulation (square-waved or cosine-waved) of stimuli in contrast to static stimuli is assumed. In particular, it is expected that the performance of discrimination of orientation and detection of a visual discontinuity in visual field defects is enhanced by stimulus presentation at frequencies in the gamma-band range (~ 20 - 80 Hz).

Furthermore, the collected commentaries given by patients while responding to the stimuli were compared with the results of the discrimination task. This was aimed to acquire more information on patients' awareness, which could further elucidate correlates of consciousness.

In a final procedure changes in visual field morphology were examined, in more detail, an enlargement of intact fields was hypothesised by means of a shift of relative blind fields to intact fields, after patients were stimulated at preferred frequencies in subregions of relative blindness.

[23] Given that performance in forced-choice tasks improves dramatically when patients are given feedback to their response, for example if the experimental procedure is designed to include a warning signal in case of an incorrect answer, it could be assumed that this improvement indicates that the mechanisms responsible for coding the stimuli in the blind field are influenced by some higher-order modulation. This might work by virtue of a mechanism allowing the patient to approach the task strategically by using the implicit information obtained from the feedback of correct and incorrect answers. This would enable patients to refine their set of criteria of which perceptions or sensations relate to the target and which do not. It is likely then that the perceptual and strategic mechanisms operate together in recurrent interaction.

# CHAPTER II:

# Classical blindsight experiment, control experiment and tests of standardized methods (BIT and MWT-B)

## Classical blindsight experiment

This experiment aimed to examine if participating patients spontaneously demonstrated blindsight phenomena. Accordingly, an a-priori and typical blindsight (forced-choice) experiment was conducted. The stimuli were used subsequently in Experiment 1 and 2 alongside blank trials and a modification of the basic paradigm to include these blank trials.

### Method of static visual field perimetry and participating patients

#### Apparatus and Stimuli

The static visual field perimetry[1] measures were performed with an Interzeag OCTOPUS-perimeter 101 and the compatible OCTOPUS Examination Software. Stimulus exposure time was 100 ms and stimuli were of Goldmann size III (standard). The dynamic range of stimulus intensity was 0 - 40 dB with (white) background illumination of 4 asb[2]. The performance of all patients was recorded for each eye separately (OD[3] and OS[4]). The Glaucoma test used here (G2 program) examined 59

[1] The static visual field perimetry is the most accurate and reliable method to examine the central visual field where the hill of vision is almost flat (vision decreases slowly to the edge of the central visual field).
[2] 1 asb = $(1/\pi)$ cd/m$^2$ ≈ 1.27cd/m².
[3] (OD) = Oculus dexter = right eye.
[4] (OS) = Oculus sinsister = left eye.

locations within the central 30° region of the visual field; this is referred to as Phase 1. Phase 1 is further divided into four successive steps; in the first two steps (1 - 2) 32 locations were tested and in the last two steps (3 - 4) 27 locations were tested. The four steps were introduced to give the opportunity to break up measure after each step, in case the patients were unable to go through all steps of Phase 1, while returning a valid measure of the static visual field perimetry, irrespective to completion of Step 2. All steps of Phase 1 measures employed a 4-2-1 dB staircase strategy: In this technique, at the beginning of the static perimetry the patient is presented with a relatively bright stimulus, which the patient is able to discern normally. Then stimuli are gradually dimmed, in steps of 4 dB, until the patient does not see the stimulus. Then, in the reverse direction, the stimuli are brightened in steps of 2 dB until the patient is able to see the stimulus. Finally, when the patient is able to see the stimulus, a final step involving a 1 dB brightness reduction is performed in order to establish a precise threshold value at the retinal location concerned (see Octopus Gesichtsfeld-Leitfaden, Interzeag AG, Schweiz).

One of the patients, FS, was examined with a comparable system: the Humphrey 700 with a white stimulus, size III, 200 ms presentation time, dynamic range of 0 - 40 dB and background illumination of 31.5 asb (~10 cd/m²). An overview test was conducted within 60° of visual angle and 120 tested locations.

All visual field perimetry measures were received from the medical reports of the participating patients.

Design and Procedure

Patients were asked to react to the presentation of a white stimulus by pressing a button, while fixating a green cross-hair in the centre of the display. Before the stimulus was presented an acoustic signal was given. Eye fixation was monitored and controlled with an infrared sensitive camera. In case of eye-movements away from the fixation cross-hair the testing system stopped until the experimenter, who remained with the patient during the measure, recalibrated fixation to the desired location and restarted the recording. Performance was recorded for each eye separately.

Patients

Three paid patients participated in the study. The patients were one female (RP) and two males (FS and LE).

The age when conducting static visual field perimetry was for patient RP 55 years old for patient FS 50 years old and for patient LE 50 years old. The age when conducting classical blindsight experiment was for patient RP 57 years, for patient FS 69 years and for patient LE 53. The age when conducting Experiment 1 and 2 (see Chapter III) was for patient RP 55 years, for patient FS 67 years and for patient LE 51. The age when conducting Experiment 3 and 4 (see Chapter IV) was for patient RP 56 years, for patient FS 68 years and for patient LE 52. The age when conducting Experiment 5 (see Chapter V) was for patient RP 57 years, for patient FS 69 years and for patient LE 53. All patients are right handed with normal or corrected-to-normal vision. Each patient gave his written informed consent and was paid € 8.00 (Euro) for each hour plus travel expenses, for each experiment.

Results of static visual field perimetry and deficits of participating patients

The results of the visual field measure for each patient are illustrated in Figure 2.I (a-e). Here the rectangles represent 2° squared of visual angle (°²). The white rectangles signify the intact fields (i.e. fully functional) visual field(s), the grey signify the relative blind and the black rectangles signify the absolute blind field(s). In the case of patient FS the black squares signify absolute defects, the crosses signify relative defects and the circles signify the intact fields.

The female patient (RP) has an upper right homonymous quadrantanopia, which overlaps into the lower right quadrant. This is in accordance with the damage, caused by a stroke, in the left occipital cortex**,** when she was at the age of 54. Macular sparing of 14.25°² of visual angle (OS) and 12.25°² of visual angle (OD) to the upper right quadrant from fixation point is evident**.**

The first male patient (FS) has a right, incomplete homonymous hemianopia, without obvious considerable macular sparing. This is in accordance with the damage of the left hemisphere, caused as a result of a head injury form a road accident (which lead to a severe craniocerebral trauma), when he was at the age of 42. For MRI, see Appendix, Chapter II, Image 1.

The second male patient (LE) suffers from a non-cortical blindness. In his case surgery was conducted to remove a tumour located under the left optic nerve, when he was at the age of 46, which result in a left, incomplete hemianopia, going far into the upper right quadrant. In the lower right quadrant there are relative defects, without macular sparing. For MRI, see Appendix, Chapter II, Image 2.

## Method of classical blindsight experiment

### Design and Procedure

The classical blindsight experiment was a decision task with five response alternatives (5-AFC). On a given trial a blank or a stimulus was presented on an oscilloscope monitor. The stimulus could appear in one of four orientations: vertical, horizontal, left tilted diagonal, right tilted diagonal or appear as a blank trial. Patients were asked to guess the orientations and the appearance of a blank trial appears.

Patients sat in front of the oscilloscope monitor and were instructed to avoid eye-movements while maintaining fixation on the coloured fixation point, positioned individually for each patient on a black plate surrounding the monitor. This ensured the stimuli could be presented within the visual field defect corresponding to the absolute blind field. All stimuli conditions were varied pseudo-randomly on a session-wise basis in order to avoid order effects. After an acoustic cue (computer-generated tone for 250 ms) a blank or a stimulus trial was presented on an oscilloscope monitor (2000 ms). Patients were allowed to have as much time as they required to judge and make their responses. They gave their responses orally which were recorded by the experimenter. This avoided the patients shifting fixation from the fixation point to the computer keyboard and helped reduce variation in trial-by-trial fixation location. During the experiment a second experimenter made a note of trials in which fixation was not maintained. In case of an erroneous response feedback was provided in the form of a computer-generated tone (1000 ms). The classical blindsight experiment consisted of 7 blocks of 40 trials each (in total 280 trials). The 7 blocks were separated by breaks, which lasted at least 10 seconds. The experimenter, who remained with the patient

during the entire experiment, initiated each new block as soon as the patient was ready to resume testing. A training block of 40 randomized practice trials was presented prior to the 7 experimental blocks. In total, the experiment lasted for approximately 1 to 1 ½ hours.

Apparatus and Stimuli

Experimental stimuli were presented on a GBM 2211 FOCUS-oscilloscope monitor of dimension 15.2 cm x 12.4 cm. Stimulus image frame generation, event timing and data collection were controlled by an IBM compatible PC, which also controlled oscilloscopic image presentation through an Interactive Electronics Systems point plotter buffer with 8 Mb frame store memory (Finley, 1985). The classical blindsight experiment was performed in a dimly lit room under controlled lighting conditions (mean screen surround luminance 13 cd/$m^{-2}$, with stimulus luminance maintained at 3.05 cd/$m^{-2}$).

Although the plotter was capable of a plot rate of 1 MHz, the desirability for fine-scaled temporal with good image resolution lead to a trade-off between temporal resolution and the number of illuminated pixels. This compromise was achieved with each image frame comprising 799 illuminated pixels, which, with a cascading phosphor decay rate of 200 microseconds (μs) per pixel, gave an overall plot time of 999 μs. (Note that cascading phosphor decay comes about because point illumination is a serial process and illuminated points decay, serially, at a rate of 1 pixel per 200 μs). As blindsight can be induced by diffuse light (stray light) it was attempted to avoid potential artefacts by ensuring that patients are not distracted from environment.

Accordingly, the monitor was surrounded with a white non-reflecting back plate (180° [90° to the left and 90° to the right]) expanding over the entire visual field (see Figure 2.1).

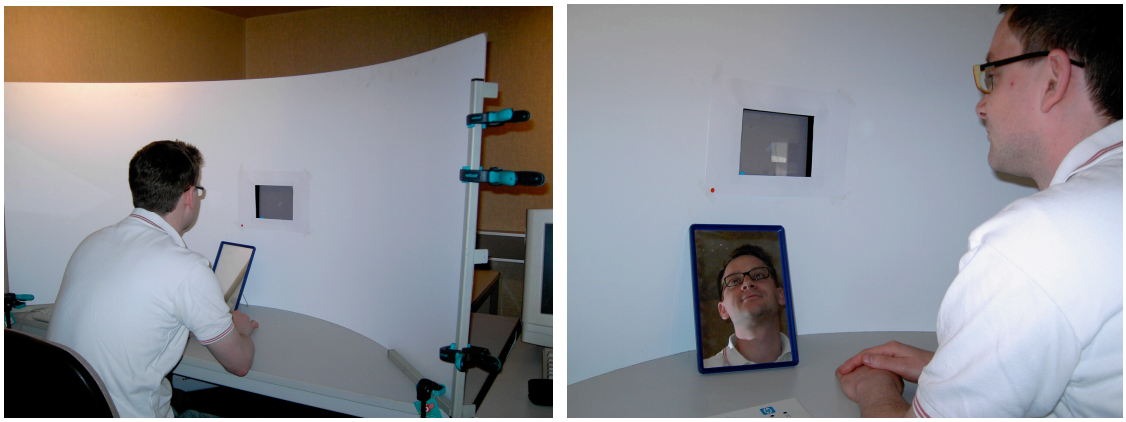


Figure 2.1: Example of the experimental situation. The patients had to maintain fixation at a colored point, fixed to the back plate. Eye movements were controlled via mirror by one of the two experimenters, sitting behind the patient.

The back plate prevented distraction by any other potential stimuli in the room and to allow an individual positioning of the fixation point. The fixation point was a red square of 0.5 cm² placed on the back plate by the experimenter. Fixation was controlled by the experimenter through a mirror (23.5 cm x 15.5 cm) with which she observed the patients eyes throughout the whole experiment. The experimental stimuli were arranged around the center of monitor and were viewed at a distance of 57 cm**.** The stimuli covered an area of 2.3° x 0.9° of visual angle and in the case of the left and right tilted diagonal of +/- 45°² of visual angle. As is illustrated in Figure 2.2, the stimulus could appear in one of four orientations: vertical, horizontal, left tilted diagonal, right tilted diagonal.

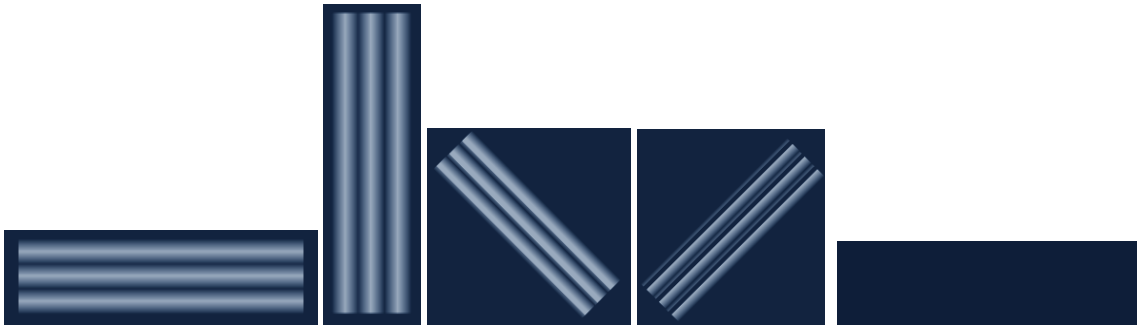
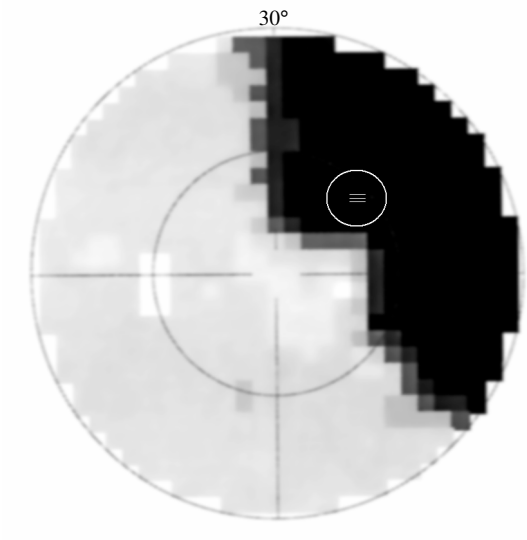


Figure 2.2: The four parallel bar gratings in their different orientations and the blank condition.
(a) shows the horizontal, (b) the vertical, (c) the left tilted diagonal, and (d) the right titled diagonal stimulus.

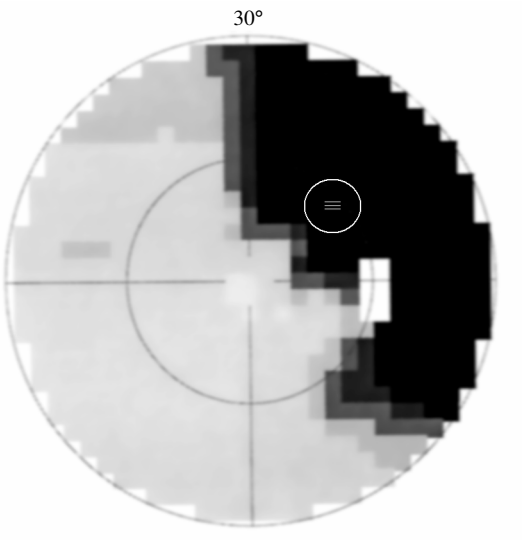
The stimuli were equivalent to Gaussian-weighted increase and decrease in image luminance. This was achieved by means of a form of pixel anti-aliasing which involved varying the density of points and illumination for 5 parallel illuminated strips that go together to form the length of the grating. A central strip had all pixels illuminated and luminance set at 1.0*z. The 2 nearest surrounding strips had 66% of pixels illuminated with illumination reduced by modifying the Z channel of the oscilloscope by sin(.75)*z. The 2 furthest, enclosing strips had 50% of pixels illuminated with illumination reduced by modifying the Z channel of the oscilloscope by sin(.5)*z. The stimuli were presented semi-statically i.e., at a background frequency of 1 kHz, representing the resolution of the oscilloscopic monitor.

The four orientations and the blank condition were varied randomly within and between each block. The experiments took place under binocular viewing conditions and stimuli were positioned within the blind field such that they lay within areas of absolute blindness (i.e. not close to the border of the blind field where blindness might be relative).

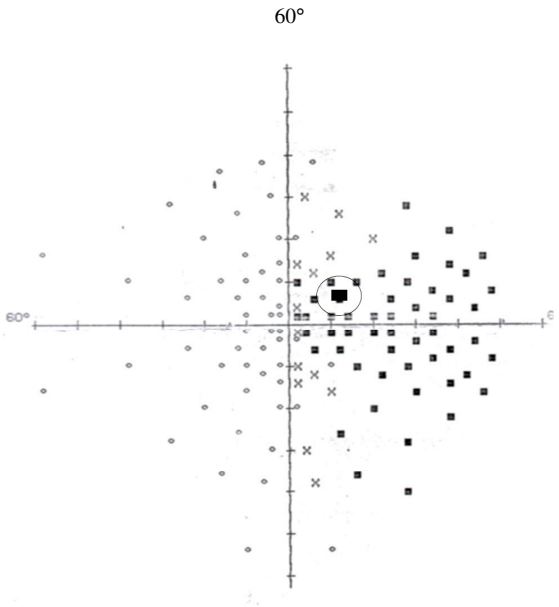
As illustrated in Figure 2.I (a-e) the exact positions of the middle of the stimuli were for patient RP on x (axis of abscissa) = + 10.7°² of visual angle and on y (axis of ordinates) = + 9.6°² of visual angle, for patient FS on x = + 12.85°² of visual angle and on y = + 7.1 °² of visual angle and patient LE on x = - 16.7°² of visual angle and on y = + 8.7°² of visual angle within the central 30° region of the visual field (for the results in an overview see next page).



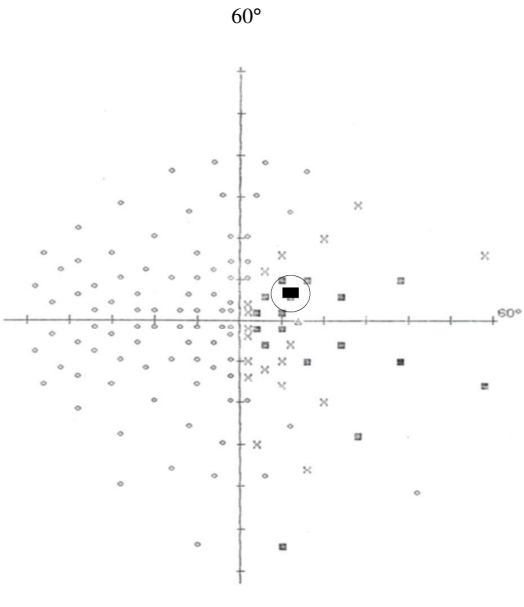

(a) RP: OS



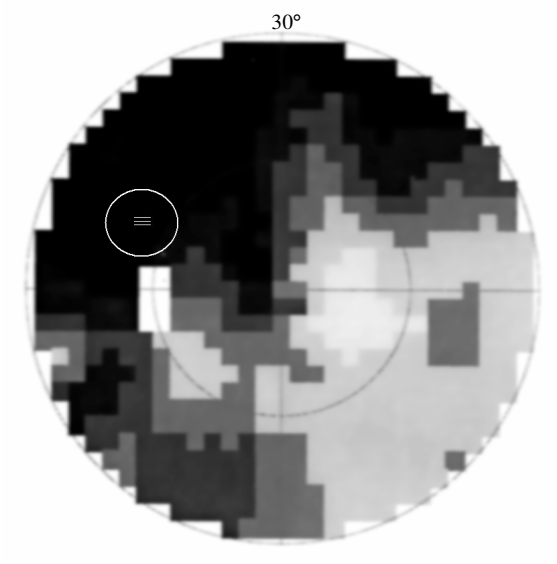

(b) RP: OD




(c) FS: OS




(d) FS: OD




(e) LE: OS

Figure 2.I: The results of the static visual field measure for (a) OS and (b) OD of patient RP, FS and LE. Each rectangle represents $2°^2$ of visual angle. The white rectangles signify the intact fields (i.e. fully functional) visual field(s), the grey signify the relative blind and the black rectangles signify the absolute blind field(s). The white vertical rectangle symbolised the blind spot. The small white bars inside the white circle signify exactly the position and size of the stimulus for each patient, within the central 30° region of the visual field. In the case of patient FS the black squares indicate absolute defects, the crosses indicate relative defects and the circles indicate the intact fields. The triangle symbolise the blind spot. The small black rectangle inside the big black circle signifies the exact position of the stimulus presented in the experiments, within the central 30° region of the visual field; original size of the stimuli was a little bit smaller.
(a) and (b) patient RP (OS), has an upper right homonymous quadrantanopia, which overlaps into the lower right quadrant. Macular sparing of $14.25°^2$ of visual angle (OS) and $12.25°^2$ of visual angle (OD) to the right upper quadrant from fixation point is evident. (c) and (d) patient FS (OS), has a right incomplete homonymous hemianopia; without considerable macular sparing. (e) Patient LE (OS) has a left, incomplete hemianopia which goes far into the right upper quadrant. In the left lower quadrant there are relative defects. No explicit macular sparing was observed.

## Results

### Testing against chance performance

In a first step, analysis of responses was based upon the calculation of percent correct for each orientation condition per frequency condition and compared against assumed chance performance for a multinominal distribution of five equiprobable response alternatives, i.e. 20 % per condition. This was estimated using a Monte Carlo Simulation of 1000 sets of 100 random numbers drawn from a multinominal distribution of five equiprobable alternatives (1:4), which permitted calculation of variance statistics in this case the 99 % confidence interval**.** The empirical distributions of the three patients were then compared with the predicted distribution.

This is illustrated in Figure 2.3 where the flanking dotted lines indicate the 99 % confidence interval of the average response. For all three patients the percent of correct responses for the different orientations lay within the confidence interval and therefore were within chance performance (0 %). The percent correct response of patient RP exceed the upper border of the confidence interval for the blank condition (55.36 %) and therefore was above chance. For all values see Table 2.1.

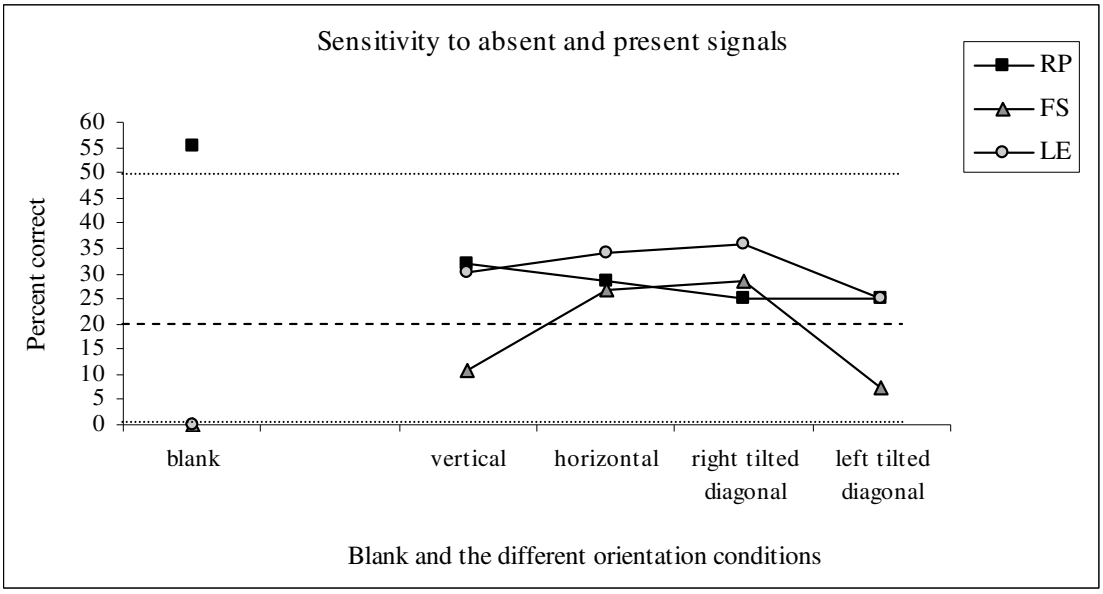



Figure 2.3: Patient RP, FS and LE: Function denotes percent correct responses for each orientation and blank condition, compared against model chance performance. The dashed horizontal line centred on .20 indicates the average response probability for each of 5 alternative responses. The flanking dotted lines represent the upper (99 %) and lower (1 %) confidence interval thresholds. The results revealed significant better performance only for patient RP given blank condition.

Table 2.1: Patient RP, FS and LE: Values of percent correct responses for each orientation and blank condition. Percent correct values significantly above chance are marked by * for $p < .01$.

| | RP | FS | LE |
|---|---|---|---|
| Stimuli | Percent correct | Percent correct | Percent correct |
| vertical | 32.14 | 10.71 | 30.36 |
| horizontal | 28.57 | 26.79 | 33.93 |
| right tilted diagonal | 25 | 28.57 | 35.71 |
| left titled diagonal | 25 | 7.14 | 25 |
| blank | 55.36* | 0 | 0 |

Chi-square ($X^2$) Test

One problem using percent correct as an estimate of sensitivity were response biases. For example, one patient might prefer to use one response alternative relative to others, artificially elevating their percent correct scores. As a result analysis was carried out for each patient over the five response alternatives using a $X^2$ test. The $X^2$ test was based upon the calculation of correct responses for the five conditions and compared against the number of actual responses made in each of the five conditions. This aimed to provide a bias free estimate of sensitivity given a tendency in all patients of preferentially responses in one way or another.

For all three patients the results revealed no significant performance given all conditions, with exception of patient RP and LE for blank condition ($X^2$ [4;99%] = 37.36, $p < .01$ and ($X^2$ [4;99%] = 14.74, $p < .01$, respectively). For all values see Table 2.2. Figure 2.4 illustrates that for patient RP and LE performance is significant high for the blank condition. None of the patients were able to successfully discriminate the orientations of the stimuli. This is in accordance to percent correct responses (with one exception: in contrast to percent correct responses patient LE revealed significantly to discriminate between signal absent and present trials).

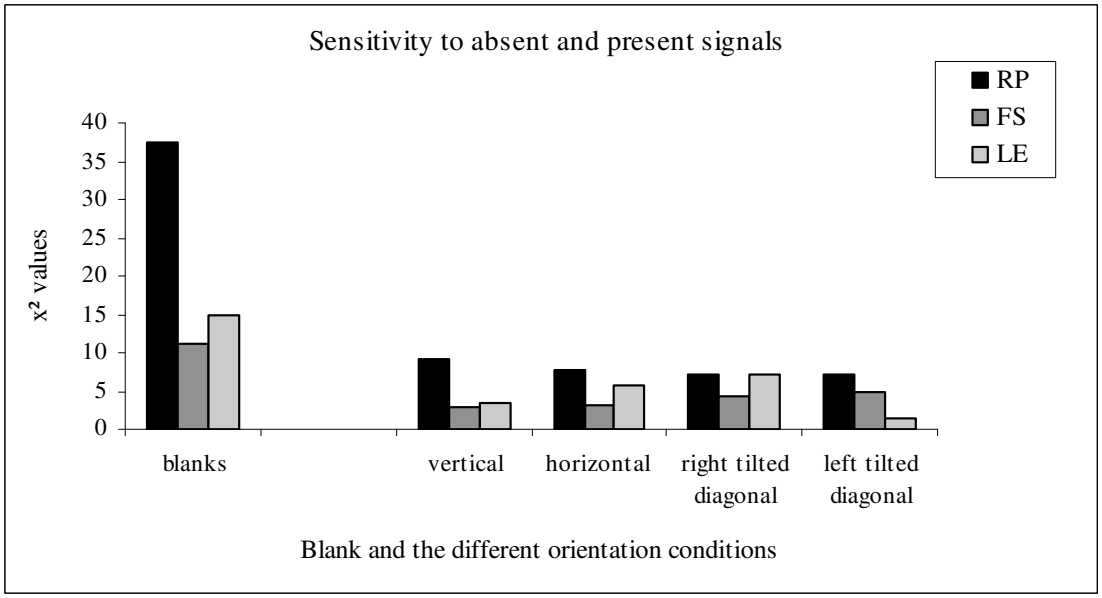



Figure 2.4: Patient RP, FS and LE: Bars denote $X^2$ values for each orientation and blank condition. The results revealed significant better performance only for patient RP and LE given blank condition.

Table 2.2: Patient RP, FS and LE: Values of $X^2$ and significances (99 %, df 4, area = 13.28 and 95 %, df 4, area = 9.49) for each orientation and blank condition. $X^2$ values significantly above chance are marked by * for $p < .01$.

| | RP | | FS | | LE | |
|---|---|---|---|---|---|---|
| Stimuli | $X^2$ | $p =$ | $X^2$ | $p =$ | $X^2$ | $p =$ |
| vertical | 9.22 | | 2.95 | | 3.45 | |
| horizontal | 7.85 | | 3.26 | | 5.65 | |
| right tilted diagonal | 7.23 | | 4.25 | | 7.06 | |
| left titled diagonal | 7.23 | | 4.97 | | 1.4 | |
| blank | 37.36 | 0* | 11.28 | | 14.74 | .0001* |

## Conclusion

None of the participating patients were able to discriminate between the different orientations. Patient RP and LE demonstrate to discriminate between signal absent and present trials. Although patient FS exhibits well documented blindsight performance (e.g. Stoerig, Kleinschmidt & Frahm, 1998) in the experiment of discrimination ability he was not able to successfully discriminate the five conditions**.** All patients showed some kind of visual experience rather than degraded real vision.

## Control experiment: Capability for vigilance and decision making

The experiment aimed to establish whether or not the patients were able to perform the experiments in the study according to the corresponding instructions, the experiment described in the classical blindsight experiment was conducted again, however this time with stimulus locations within the intact visual field.

## Method

The method of the control experiment was the same than in the classical blindsight experiment with the following exceptions: The control experiment differed from the classical blindsight experiment in that exact positions of the middle of the stimuli were for patient RP on x = 0°² of visual angle and on y = - 6.6°² of visual angle, for patient FS on x = - 8.5°² of visual angle and on y = - 7.2°² of visual angle and for patient LE on x = + 8.6°² of visual angle and on y = - 6.3°² of visual angle, within the central 15° region of the visual field (for visual field perimetry measures see classical

blindsight experiment). The control experiment consisted of 9 blocks of 40 trials each (in total 360 trials). The 9 blocks were separated by breaks, which lasted at least 10 seconds. The experimenter, who remained with the patient during the entire experiment, initiated each new block as soon as the patient was ready to resume testing. A training block of 40 randomized practice trials was presented prior to the 7 experimental blocks. In total, the experiment lasted for approximately ½ to 1 ½ hour.

Results and Conclusion

For each patient, performance was found to be perfect and therefore that all patients are able to keep vigilance and to discriminate correctly may be assumed without reservation. Patients had neither problem with discriminating the presented stimuli nor with making a decision.

## Behavioural inattention test manual (BIT)

As sometimes it is discussed that blindsight could be an effect of attentional deficits, the patients undertook the Behavioural inattention test manual (BIT) by TVTC Thames Valley Test Company, which measures unilateral visual neglect (UVN)[5]. This test was chosen because neglect seems to be based on attentional deficit(s), which are assumed to rehabilitate, when patients are presented with cueing stimuli which lead attention to the neglected visual field (for an overview see e.g. Rustenbach, Pawlik & Wein, 2000).

### Method

The BIT has nine 'behavioural sub-tests' reflecting aspects of daily life, which were not conducted and six simple pencil and paper measures of neglect, referred to as 'conventional sub-tests' which were employed here. In each of these sub-tests the strategy is to record the number of omissions[6]. The conventional sub-tests are a simple pencil and paper measure and patients are instructed by examples in the first three sub-tests.

[5] The Behavioural inattention test manual (BIT) of TVTC (Thames Valley Test Company) is a standardized test for measuring unilateral visual neglect (UVN)**.** Approximately 40 % of right hemisphere stroke patients show evidence of visual neglect. Although such tasks may provide useful information about the presence of UVN, they do not supply information that increases our understanding of specific difficulties patients will encounter in everyday life. The heterogeneity of visual neglect requires a wide range of tasks. Some are single and often decontextualized; tend to miss patients whose deficits are more apparent in 'real world' situations. An advantage of the BIT is that the battery of tasks was standardized on patients admitted to a rehabilitation centre on average two months post stroke.

[6] There was no significant difference between the two groups in age, IQ or time post stroke. Although visual neglect is generally considered to be a failure to respond in free vision to stimuli situated on the side contralateral to a cerebral lesion, it may be documented for ipsilateral space omission.

In ‘line crossing’ (Sub-test No. 1) patients were asked to cross out all the lines on a paper which they can see. In ‘letter cancellation’ (Sub-test No. 2) patients were asked to cross out all E´s and R´s which were presented in lines, which themselves were including different letters of the alphabet. In ‘star cancellation’ (Sub-test No. 3) patients were asked to cross out all stars which were presented between big stars. In ‘figure and shape copy’ (Sub-test No. 4) patients were asked to copy three separate, simple drawings from the left hand column of the sheet to the right column. The three drawings, a star, a cube and a daisy, are arranged vertically. After completing the copying task, patients were required to copy a group of three geometric shapes on a separate sheet of paper. In ‘line bisection’ (Sub-test No. 5) patients were presented with a page containing three horizontal eight inch lines spread in a staircase fashion across the page. The extent of each line was pointed out to the patient who was then instructed to estimate the centre. It was not allowed to them to use a pen or any other object to estimate the mid-point. In ‘representational drawing’ (Sub-test No. 6) the patients were presented with a blank sheet of paper and was instructed to draw, a) a large clock face with numbers, b) a simple drawing of a man or a woman and c) a simple drawing of a butterfly. Based on the fact that the patients were all right handed there were no problems with the drawings tasks one would perhaps have with left handed patients.

## Results and Conclusion

As illustrated in Table 2.3, all patients performed well above the cut-off scores for all BIT sub-tests and might be concluded to not present visuo-spatial neglect.

Table 2.3: Patient RP, FS and LE: Results (scores) of sub-tests of the Behavioural inattention test manual (BIT).

| Sub-tests | Maximum scores | Acceptable range | Cut-off scores | RP scores | FS scores | LE scores |
|---|---|---|---|---|---|---|
| line crossing | 36 | 35-36 | 34 | 36 | 36 | 36 |
| letter cancellation | 40 | 33-40 | 32 | 40 | 40 | 39 |
| star cancellation | 54 | 52-54 | 51 | 54 | 54 | 53 |
| figurers and shape copy | 4* | 4 | 3 | 4 | 4 | 4 |
| line bisection | 9 | 8-9 | 7 | 9 | 9 | 9 |
| representational drawing | 3 | 3 | 2 | 3 | 3 | 3 |

*3 points for 3 simple drawing and 1 point for 3 geometric shapes.

## Mehrfachwahl-Wortschatz-Intelligenz-Tests (MWT-B)

The absence of verbal description of perception (as an indicator of awareness) can be due to different reasons, such as non-pathological problems in communication or missing knowledge about the stimuli. To test patients intelligence[7] all patients had to undergo the MWT-B, which is a part of one of the most common test of the 'Mehrfachwahl-Wortschatz-Intelligenz-Tests'.

### Method

The MWT-B is a simple pencil and paper measure. Patients were presented a sheet of paper on which they can find 37 lines, including five words each, of which one word exists and the other four words are nonsense constructions. Patients were instructed to mark the existing word of each line with a cross. They were not allowed to guess. There was an increasing degree of difficulty for each line.

[7] Cognitive intelligence can be classified in terms of 'fluid intelligence' and 'kristalline intelligence'. Fluid intelligence signifies the capability of comparison and is e.g. equivalent to the short-term memory or working memory. Kristalline intelligence describes performance in understanding language, experiential knowledge about things, about oneself and others as well as life coping strategies. This capability is equivalent to long-term memory. While fluid intelligence decreases with age, kristalline intelligence is maintained and may even increase in scope.

Results and Conclusion

As illustrated in Table 2.4, all patients are above the average of 100 IQ points. Patients show almost the same IQ scores and it can be concluded that none of the patients would have problems to understand or perform the experimental tasks in this study.

Table 2.4: Patient RP, FS and LE: Results (total-, percent correct-, IQ- and Z-values) of Mehrfachwahl-Wortschatz-Intelligenz-Tests (MWT-B).

| Patients | Total values | Percent correct | IQ values | Z-values |
|---|---|---|---|---|
| RP | 30 | 71.1 | 107 | 105 |
| FS | 34 | 97.7 | 130 | 120 |
| LE | 30 | 71.1 | 107 | 105 |

# CHAPTER III:
# The effects of flicker on discrimination performance in blindsight

## Introduction and Review

Beside retinal blindness there are forms of blindness arising due to damage to visual parts of the primary visual cortex (V1), resulting in visual loss located in the visual field contralateral to the site of the lesion. In terms of visual space and related to the dimensions and location (before or after the optic chiasm) of the damaged tissue, visual field losses can be of different size: from the restricted loss of a small area of visual field up to even half fields (referred to as hemianopia). Originally lesions of V1 were thought to cause irreversible and total blindness in the affected parts of the visual field. However by 1905 Bard (Bard, 1905, described in Stoerig, 1999 and Weiskrantz, 2004) reported that cortically blind patients are able to locate source of light. Later animal and human findings have shown that even in spite of lesions to V1, detection, discrimination or localization of visual stimuli presented in the affected part of visual field is possible (e.g. Riddoch, 1917; Humphrey, 1974; Weiskrantz, Warrington, Sanders & Marshall, 1974; Weiskrantz, 1980). Moreover findings revealed that in some of these patients residual vision is accompanied by awareness (as in Riddoch syndrome, Riddoch 1917) and in others not.

Based upon this dissociation between visual capability and awareness, Weiskrantz (e.g. Sanders, Warrington, Marshall & Weiskrantz, 1974 and Weiskrantz, 1986) coined the term blindsight to refer to visual capacity in a field defect in the absence of acknowledged awareness. Later studies concerning blindsight have revealed that

patients sometimes become aware (and sometimes not, in no relation of the kind of stimuli presented) of visual events if those events are sufficiently salient. Patients themselves do not describe their phenomenal impression as 'seeing' but rather as a kind of 'feeling' that something appeared or has moved within their blind field (Weiskrantz, 1986 and Stoerig & Cowey, 1997). Awareness in this sense is conducted by collecting commentaries patients give when responding to stimuli presented in the blind field (e.g. Weiskrantz, 1986). Note that awareness in blindsight follows a different functional relationship with respect to stimulus speed, displacement, and stimulus contrast (Weiskrantz, Barbur & Sahraie, 1995) in comparison with blindsight without awareness. Marcel (1988) has concluded '…that the main deficit in blindsight is one of consciousness…' but not a total loss of consciousness in the blind field (Marcel, 1998, p.121).[1] In view of the differentiation of detection performance and patients state of awareness of visual events Trevethan and Sahraie (2003) distinction between blindsight I, i.e. discrimination performance without acknowledged awareness, and blindsight II, discrimination performance in the presence of awareness without 'seeing' per se (or denying any experience of 'seeing') is adopted.

Concerning anatomically distinguish in blindsight findings suggest that an activity in V1 can be excluded as a likely source of visual capability with blindsight based on activity in extrastriate cortex (Stoerig, Kleinschmidt & Frahm, 1998; Weiskrantz, 1996; Stoerig & Cowey, 1997; Stoerig, 2003) and is mediated by the extrageniculate pathway (Mohler & Wurtz, 1977; Perenin, Ruel & Hecaen, 1980; Morris, DeGelder, Weiskrantz & Dolan, 2001).

[1] Besides Marcel, Gregory, 1972 (described in Weiskrantz, 1980), confirmed the spatial localisation capacity and could show remarkable interactions between parts of the visual fields in the intact and blind fields using the Kanizsa triangles.

Concerning visual awareness blindsight can be accompanied by a total loss and sometimes by a loss of consciousness but not a total loss. In this context the role of visual awareness has been discussed anatomically: blindsight with some kind of visual awareness is assumed to be mediated by extrastriate and prefrontal cortex (Sahraie, Weiskrantz, Barbur, Simmons, Williams & Brammer, 1997 and Zeki & ffytche, 1998), while blindsight without awareness is assumed to be mediated by implicit process, related to subcortical activation (Sahraie et al. 1997). This fits as well in the assumption of an exclusion of V1 in consciousness (Crick & Koch, 1995a and 1995b) and that awareness is related to activation of the higher-systems as extrastriate (e.g. V5) or prefrontal cortices (Koch, 1994). Visual awareness is also believed to be related to (e.g. attentional) mechanism that temporarily binds the relevant neurons together by synchronizing their spikes in 40-Hz oscillations (Crick & Koch, 1990a and 1990b, described in Koch, 2004).

The idea of a dynamic visual system was originally suggested in the earlier 19$^{th}$ century for example by Fechner (1860) who suggested oscillatory activity as a mediator of conscious perception and who also claimed that neuronal oscillations provide the most likely neurophysiological process by which psychological events might be generated. Physiological studies have shown the synchronous firing of neurons responding to different aspects of the same visual Gestalt which may be a physiological correlate with perceptual integration, in particular 'binding' (i.e. the combination) of visual information and representation of a coherent object-based representation; this might be due to neurons bound into assemblies by a temporal code (e.g. von der Malsburg 1981, 1985 and Malsburg, von der & Schneider, 1986; see also the 'temporal correlation hypothesis', e.g. Gray & Singer, 1989). Furthermore it has also been shown

that internal feature coding mechanisms are entrainable by external stimulus modulation or in particular form-based processing can be influenced by synchronized stimuli presented in stimulus matrices that flicker at the same frequency as neurons synchronize in visual cortex (Elliott & Müller, 1998). Assumptions that impaired synchrony are likely to account for perceptual deficits comes, for example, from investigations of the effects of strabismic amblyopia in cat (reported in Singer, 1999). Vanni, Raninen, Näsänen, Tanskanen and Hyvärinen (2001) using MEG found in patient MR (showing blindsight), who had to detect sinusoidally flickering luminance patterns, residual visual capacities to be accompanied by an abnormal distribution of brain activity. In particular they found stimuli in the affected hemifield failed to generate an early fast transient response at the posterior cortical regions and a later and relatively strong response in the contralateral superior temporal (ST) regions. Vanni et al. concluded that '…the lack of early posterior synchronized neural activation is causally related to the enhanced longer-latency ST activity: compensation of the impaired input by enhanced higher- order processing may be necessary for the residual vision in the affected hemifield. (Vanni et al., 2001, p.865).

Although blindsight is common, the brain mechanism responsible is poorly understood. Recently when examining blindsight, an enhancement of discrimination of temporally modulated gratings, in contrast to rapid on/off-set static gratings was found (Sahraie, Weiskrantz, Trevethan, Cruce & Murray, 2002, described in Trevethan & Sahraie, 2003). Patients showing blindsight were found to discriminate better rapidly flickering stimuli presented in the blind field (Weiskrantz, 1986) and flickering targets are also better localised in space (Perenin, Ruel & Hecaen, 1980, described in Trevethan & Sahraie, 2003). Later Trevethan and Sahraie (2003) also found a narrowly tuned

temporal channel mediating blindsight performance when gratings were sinusoidal modulated within a narrow range of frequencies between 10 and 33 Hz (with sensitivity peak at 20 Hz; note that this fit into the findings of Barbur, Harlow and Weiskrantz, 1994 who found in patient GY that for sinusoidal gratings forced-choice detection scores were substantially greater than 50 % for stimuli presented in the range ~ 6 - 40 Hz); another crucial effect Trevethan and Sahraie (2003) found was that the level of awareness was higher under the experimental conditions designed to isolate the temporal characteristics of blindsight relative to conditions designed purely to analyse spatial sensitivity. They concluded that this as well may be attributed to the temporal content of the stimulus.

As the visual system is regarded as being temporal in its basic characteristics, one can assume that the architecture of the temporal visuo-cortical function is a distributed dynamic system perceptually organised in a form of equilibrium state. Based on this, the visuo-cortical dysfunction attributable to some non-specific cortical lesion would not cause a total loss of function but may result in an inability to establish a state of equilibrium. This might happen by virtue of an alteration of the temporal characteristics of the distributed system resulting in absent or 'miss-synchronization' and an elevation of noise to signal in neural circuitry that might otherwise function with some residual capability.

This study examined whether direct physical modulation of visual input in terms of conditioning of a frequency response at frequencies believed to be important for visual binding operations, enhances, if not mediates blindsight and residual visual capabilities (via forced-choice and feedback). It was hypothesised that a general enhancement of response accuracy follows the presentation of two classes of temporally

modulated (i.e. square-wave or cosine-wave) stimuli in contrast to static stimuli. An enhanced discrimination of stimulus orientation in visual field defects was expected after presentation at frequencies in the gamma-band range (~ 20 - 80 Hz).

Furthermore, the commentaries provided by patients while undertaking the task were collected and compared with the results of the discrimination task. This aimed to acquire more information on patients' awareness, which could further elucidate performance correlates with consciousness.

## Experiment 1:
## Discrimination of square-waved modulated gratings of different orientations

### Method

For details of participating patients as well as methods see Chapter II (classical blindsight experiment). Additional examinations revealed that none of the patients suffered from visuo-spatial neglect (BIT), patients were of equal intelligence (MWT-B, which is part of the Mehrfachwahl-Wortschatz-Intelligenz-Test) and were able to discriminate the stimuli used in Experiment 1 and 2 when presented in the intact visual field. Additionally patient FS exhibits well documented blindsight performance (e.g. Stoerig et al. 1998) although in the study of discrimination ability in the absence of temporal modulation, he was not able to successfully discriminate the orientation of the stimuli used in Experiments 1 and 2. For these results in detail see Chapter II (classical blindsight experiment).

### Design and Procedure

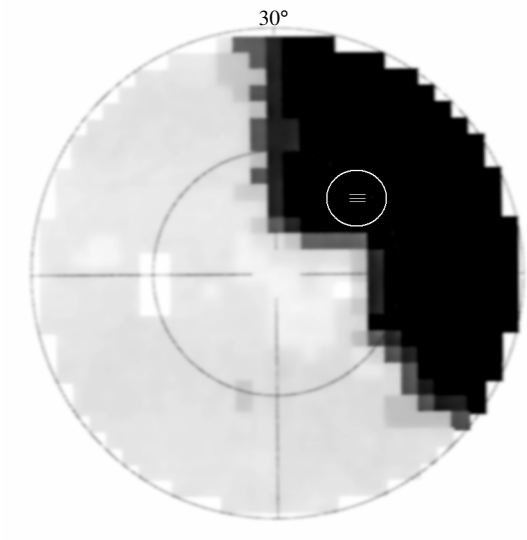
The design and procedure of Experiment 1 was the same than in the classical blindsight experiment with the following exceptions: Experiment 1 differed from the classical blindsight experiment in that it was a decision task with four response alternatives (4-AFC). On a given trial, a stimulus was presented on an oscilloscopic monitor. The stimulus could appear in one of four orientations: vertical, horizontal, left tilted diagonal, right tilted diagonal and patients were asked to guess the orientation and to comment on their responses (what and why they guessed their orientation judgment). The Experiment 1 consisted of 19 blocks of 40 trials each (in total 760 trials; consisted

of approximately 76 trials per frequency condition). In total, the Experiment 1 lasted for approximately 2 ½ to 3 ½ hours.

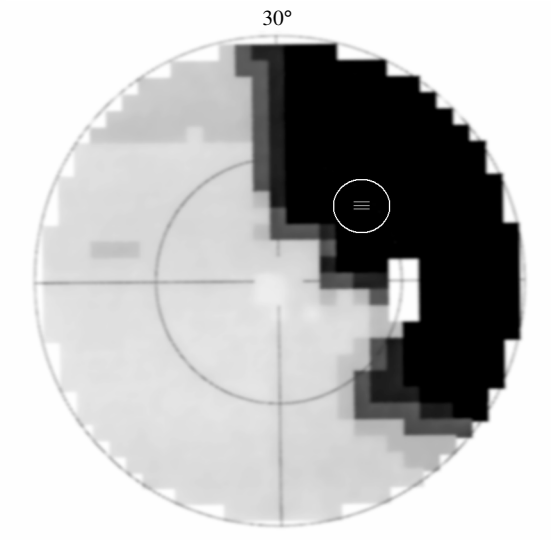
Apparatus and Stimuli

The apparatus and stimuli of Experiment 1 was the same than in the classical blindsight experiment with the following exceptions: Experiment 1 differed from the classical blindsight experiment in that there was no absent condition (blank trials) and in that the stimuli deployed in Experiment 1 consisted of a square-waved modulated grating of three parallel bars. The gratings appeared simultaneously and repeatedly at one of nine frequencies (20, 21, 25, 27, 33, 38, 50, 71 and 100 Hz) or were presented as semi-static (i.e. did not flicker but were presented at the background plot rate of 1 kHz). Stimulus presentations by frequency and orientation were varied pseudo-randomly within and between each experimental block.

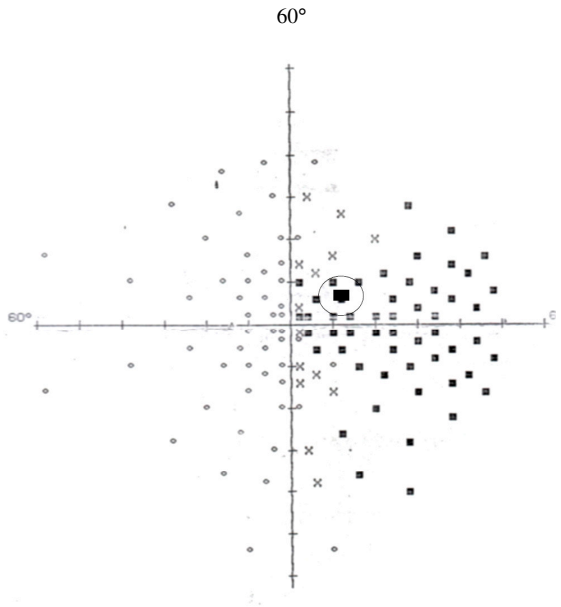
As illustrated in Figure 3.I (a-e) the exact positions of the middle of the stimuli were for patient RP on x (axis of abscissa) = + 10.7°² of visual angle and on y (axis of ordinates) = + 9.6°² of visual angle, for patient FS on x = + 12.85°² of visual angle and on y = + 7.1 °² of visual angle and patient LE x = - 11.2°² of visual angle and on y = + 9.2°² of visual angle, within the central 15° region of the visual field (for the results in an overview see next page).



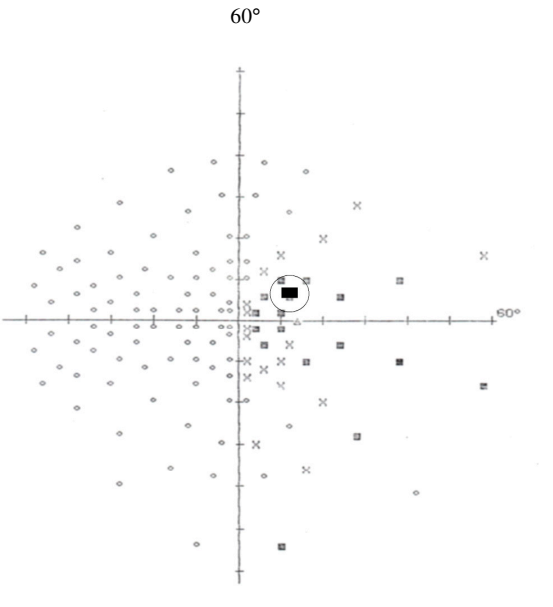

(a) RP: OS



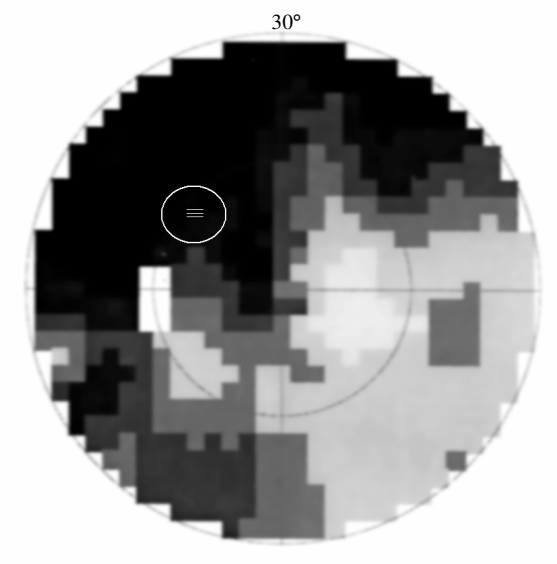

(b) RP: OD




(c) FS: OS




(d) FS: OD




(e) LE: OS

Figure 3.I: The results of the static visual field measure for (a) OS and (b) OD of patient RP, FS and LE. Each rectangle represents $2°^2$ of visual angle. The white rectangles signify the intact fields (i.e. fully functional) visual field(s), the grey signify the relative blind and the black rectangles signify the absolute blind field(s). The white vertical rectangle symbolised the blind spot. The small white bars inside the white circle signify exactly the position and size of the stimulus for each patient, within the central 30° region of the visual field. In the case of patient FS the black squares indicate absolute defects, the crosses indicate relative defects and the circles indicate the intact fields. The triangle symbolise the blind spot. The small black rectangle inside the big black circle signifies the exact position of the stimulus presented in the experiments, within the central 30° region of the visual field; original size of the stimuli was a little bit smaller.
(a) and (b) patient RP (OS), has an upper right homonymous quadrantanopia, which overlaps into the lower right quadrant. Macular sparing of $14.25°^2$ of visual angle (OS) and $12.25°^2$ of visual angle (OD) to the right upper quadrant from fixation point is evident. (c) and (d) patient FS (OS), has a right incomplete homonymous hemianopia; without considerable macular sparing. (e) Patient LE (OS) has a left, incomplete hemianopia which goes far into the right upper quadrant. In the left lower quadrant there are relative defects. No explicit macular sparing was observed.

## Results

### Testing against chance performance

For each patient, responses of the 760 trials on which fixation was not maintained (FS: 2 trials, LE: 1 trial; no more than 1.25 % of trials per patient), were removed from the data prior to further analyses. The analysis versus chance performance was the same as conducted for the classical blindsight experiment, with one exception: The analysis of responses was compared against assumed chance performance for a multinominal distribution of four equiprobable response alternatives, i.e. 25 % per condition.

As illustrated in Figure 3.1 for the two cortical blind patients RP and FS the percent correct responses for the different orientations per semi-static and frequency condition lay in general within the confidence interval and therefore were within chance performance. The percent correct response for patient FS, however, lay beyond the confidence interval and therefore above chance for the frequency conditions 38 Hz (39.38 %). The percent correct responses for patient LE exceed the upper border of the confidence interval for semi-static (38.27 %) and all frequency conditions (20 Hz [46.55 %], 27 Hz [41.58 %], 33 Hz [40.61 %], 38 Hz [44.03 %], 50 Hz [37.62 %] and 100 Hz [43.03 %]). For all values see Table 3.1.

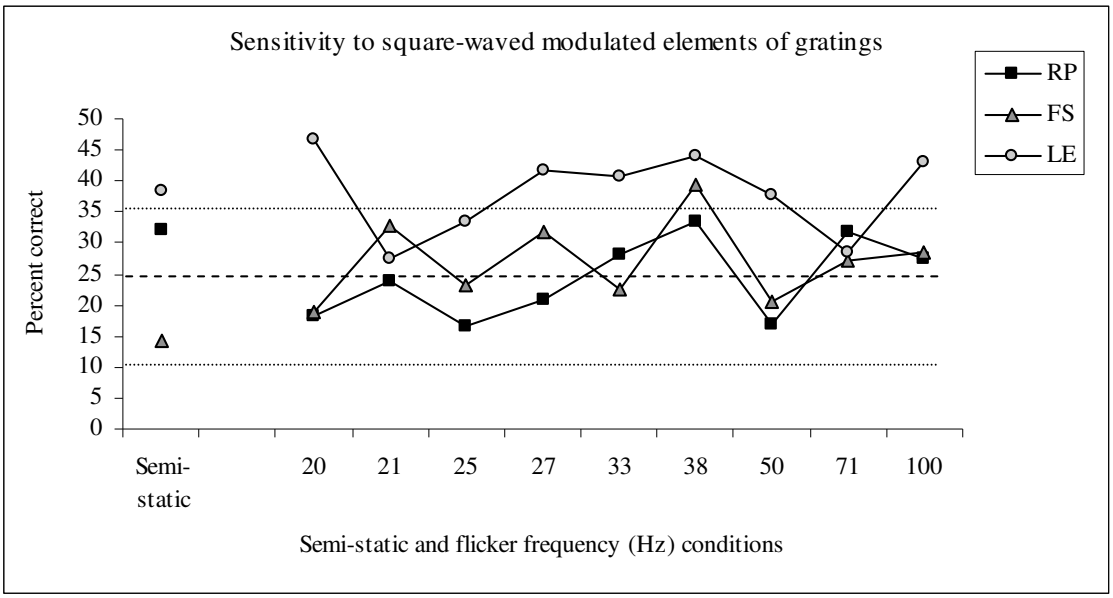



Figure 3.1: Patient RP, FS and LE: Function denotes percent correct responses for each orientation per semi-static and frequency conditions, compared against model chance performance. The dashed horizontal line centred on .25 indicates the average response probability for each of 4 alternative responses. The flanking dotted lines represent the upper (99 %) and lower (1 %) confidence interval thresholds.. The trend shows that for all patients performance is high at 38 Hz, with exception of patient LE, who performed even better following 20 Hz. Performance of RP and FS revealed almost the same function with an increase at 21 Hz, 27 Hz, 38 Hz and 71 Hz and a decrease at 20 Hz, 25 Hz, 33 Hz and 50 Hz (with one exception: a discrepant point in the data of RP at 33 Hz).

Table 3.1: Patient RP, FS and LE: Values of percent correct responses for each orientation per semi-static and frequency conditions. Percent correct values significantly above chance are marked by * for $p < .01$.

| | RP | FS | LE |
|---|---|---|---|
| Frequency (Hz) | Percent correct | Percent correct | Percent correct |
| Semi-static | 32.17 | 14.23 | 38.27 * |
| 20 | 18.24 | 18.71 | 46.55* |
| 21 | 23.81 | 32.91 | 27.64 |
| 25 | 16.42 | 23.11 | 33.44 |
| 27 | 20.79 | 31.95 | 41.58* |
| 33 | 28.09 | 22.47 | 40.61* |
| 38 | 33.59 | 39.38* | 44.03* |
| 50 | 17.03 | 20.61 | 37.62* |
| 71 | 31.85 | 27.09 | 28.38 |
| 100 | 27.5 | 28.53 | 43.03* |

Furthermore analysis of percent correct responses for each orientation condition by frequency were compared to the corresponding data given semi-static presentation, as the semi-static condition is the experimental control condition. This is illustrated in Figure 3.2 where the bars denote the individually averaged response given semi-static condition. For patient RP the percent correct responses per frequency conditions lay beneath the performance she revealed given semi-static condition (32.17 %), with exception of a slightly better performance at 38 Hz (33.59 %). For patient FS results revealed a better performance irrespective given all frequency conditions (20 Hz [18.71 %], 21 Hz [32.91 %], 25 Hz [32.11 %], 27 Hz [31.95 %], 33 Hz [22.47 %], 50 Hz [20.61 %], 71 Hz [27.09 %], 100 Hz [28.53 %], with best performance at 38 Hz [39.38 %]), than at semi-static condition (14.23 %). For patient LE results revealed a better performance for frequency conditions 20 Hz (46.55 %), 27 Hz (41.58 %), 33 Hz (40.61 %), 38 Hz (44.03 %) and 100 Hz (43.03 %), than at semi-static condition (38.27 %). Note that in his case, interpretation or comparison of frequency conditions against semi-static condition is illustrative, as the semi-static condition is also significantly better than model performance which reduces its utility as a control condition. For all values see Table 3.1.

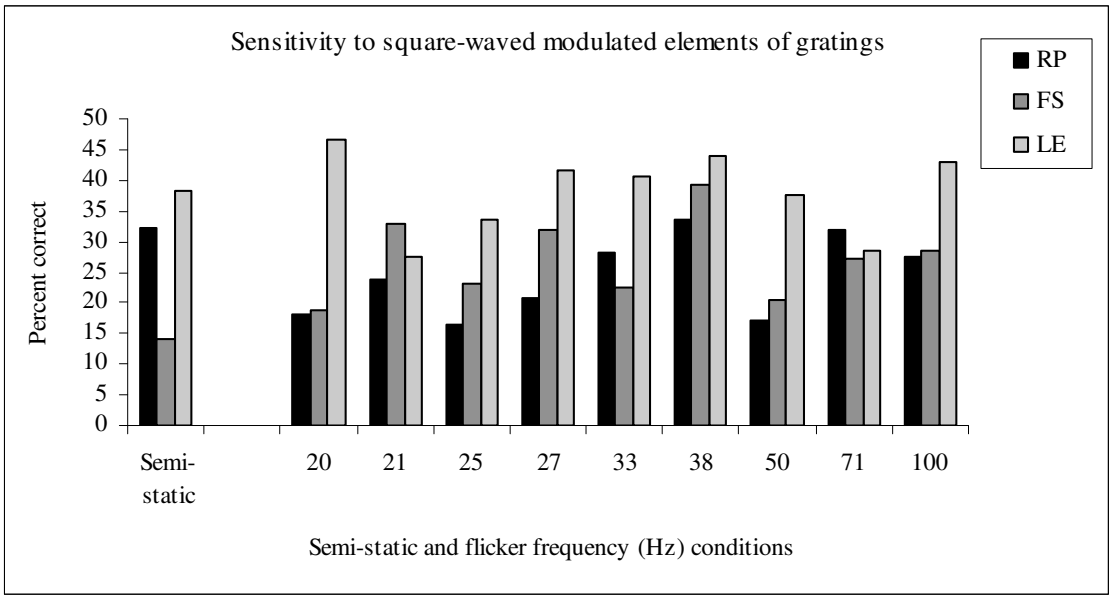



Figure 3.2: Patient RP, FS and LE: Bars denote percent correct responses for each orientation per frequency conditions, compared to the individually corresponding data given semi-static presentation. Patient RP the percent correct responses per frequency conditions lay beneath the performance she revealed given semi-static condition (32.17 %), with exception of a slightly better performance at 38 Hz (33.59 %). For patient FS and LE results revealed in general a better performance given all frequency conditions. For Patient LE, however, performance was worse at 21 Hz, 25 Hz and 71 Hz as well as slightly at 50 Hz, than given semi-static condition.

Chi-square ($X^2$) Test

The analysis of ($X^2$) test was the same than in the classical blindsight experiment. For details of analysis see Chapter II (classical blindsight experiment).

The results revealed that patient RP performed significantly above chance following semi-static presentation ($X^2$ [3;99 %] = 13.83, $p < .01$). Patient FS reaches significance for 25 Hz ($X^2$ [3;99 %] = 13.87, $p < .01$), 38 Hz ($X^2$ [3;99 %] = 16.46, $p < .01$) and 100 Hz ($X^2$ [3;99 %] = 12.43, $p < .01$) and patient LE performed significantly better than chance for 20 Hz ($X^2$ [3;99 %] = 22.38, $p < .01$), 33 Hz ($X^2$ [3;99 %] = 12.8, $p < .01$) and 38 Hz ($X^2$ [3;99 %] = 16.22, $p < .01$). For all values see Table 3.2.

Figure 3.3 illustrate that both patient FS and LE performed best at 38 Hz, with one exception: patient LE's performance following 20-Hz presentations. His performance is

in accordance with the results revealed for percent correct responses. In contrast to percent correct analysis patient RP and FS do not show the same trend and patient RP revealed to perform best given semi-static condition and worse given 38 Hz.

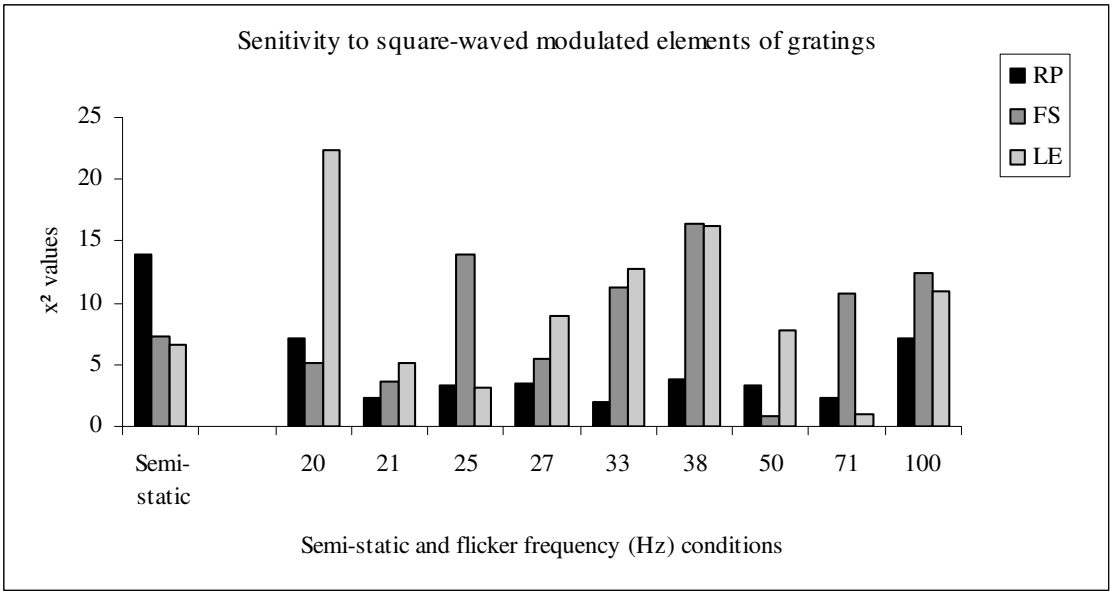



Figure 3.3: Patient RP, FS and LE: Bars denote $X^2$ values for each orientation condition per frequency and semi-static conditions. Both patient FS and LE performed best at 38 Hz, with one exception: patient LE performance given 20 Hz. Patient RP revealed to perform best given semi-static condition.

Table 3.2: Patient RP, FS and LE: Values of $X^2$ and significances (99 %, df 3, area = 11.34 and 95 %, df 3, area = 7.81) for each orientation condition per semi-static and frequency condition. $X^2$ values significantly above chance are marked by * for $p < .01$.

| | RP | | FS | | LE | |
|---|---|---|---|---|---|---|
| Frequency (Hz) | $X^2$ | $p =$ | $X^2$ | $p =$ | $X^2$ | $p =$ |
| Semi-static | 13.83 | .0031* | 7.23 | | 6.56 | |
| 20 | 7.2 | | 5.11 | | 22.38 | .0000* |
| 21 | 2.28 | | 3.7 | | 5.11 | |
| 25 | 3.32 | | 13.87 | .0030* | 3.22 | |
| 27 | 3.5 | | 5.39 | | 8.89 | |
| 33 | 1.93 | | 11.2 | | 12.8 | .0050* |
| 38 | 3.78 | | 16.46 | .0009* | 16.22 | .0010* |
| 50 | 3.34 | | 0.81 | | 7.84 | |
| 71 | 2.4 | | 10.84 | | 1.01 | |
| 100 | 7.2 | | 12.43 | .0060* | 10.97 | |

Commentaries

As patient FS and patient LE gave insufficient number of commentaries they were excluded from further analysis. In a first step, the commentaries provided by patient RP were analysed by clustering in the following way (for all commentaries see Appendix, Chapter III): 1. Impressions where she had the feeling of noticing something ‘brighter’ were clustered as condition I. 2. Impressions where she had the feeling of noticing something ‘darker’ were clustered as condition II. 3. Impressions where she had the feeling of noticing something ‘foggy’ were clustered as condition III. 4. Impressions where she had the feeling of noticing something ‘figural’ were clustered as condition IV.

In a second step responses were counted for each commentary condition for the semi-static and each frequency conditions. This is illustrated in Figure 3.4 where the bars denote the frequency based commentary conditions. For patient RP results revealed responses to be enhanced for condition I following semi-static presentation and for all frequency conditions, with peaks at 21 Hz, 27 Hz and 100 Hz. For all values see Table 3.3.

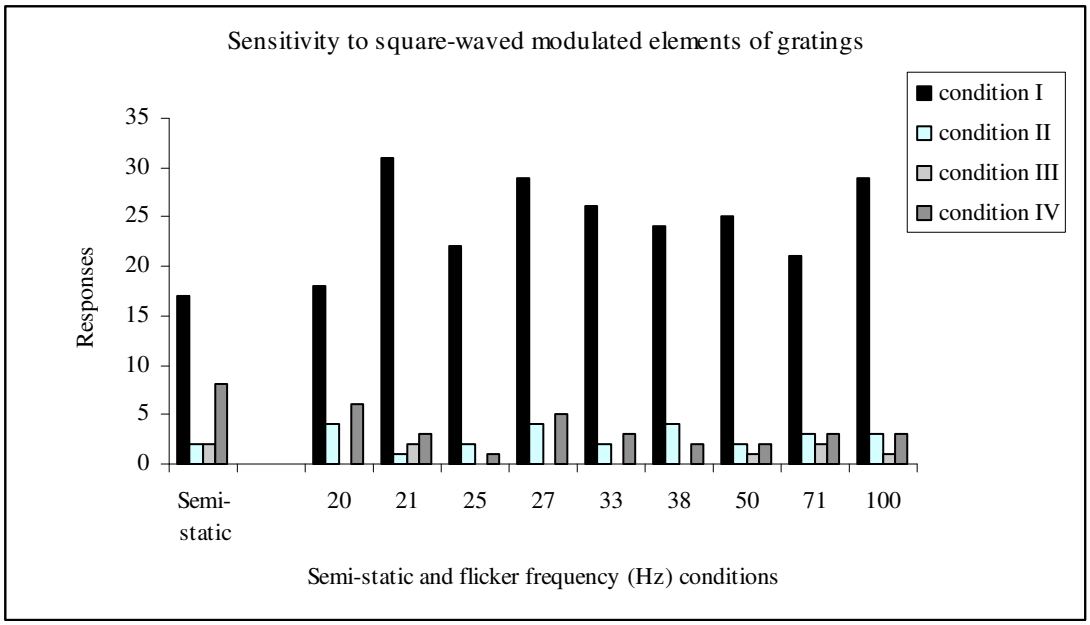



Figure 3.4: Patient RP: Bars denote frequency based responses for each condition (I, II, III and IV) per semi-static and frequency conditions. Responses were enhanced for condition I per semi-static and all frequency conditions, with peak at 21 Hz.

Table 3.3: Patient RP: Responses for each condition (I, II, III and IV) per semi-static and frequency conditions.

| | Condition I | Condition II | Condition III | Condition IV |
|---|---|---|---|---|
| Frequency (Hz) | Responses | Responses | Responses | Responses |
| Semi-static | 17 | 2 | 2 | 8 |
| 20 | 18 | 4 | 0 | 6 |
| 21 | 31 | 1 | 2 | 3 |
| 25 | 22 | 2 | 0 | 1 |
| 27 | 29 | 4 | 0 | 5 |
| 33 | 26 | 2 | 0 | 3 |
| 38 | 24 | 4 | 0 | 2 |
| 50 | 25 | 2 | 1 | 2 |
| 71 | 21 | 3 | 2 | 3 |
| 100 | 29 | 3 | 1 | 3 |

In a third step commentary conditions were counted for correct responses only following semi-static presentation and for each frequency condition. This is illustrated in Figure 3.5 where the bars denote the frequency based commentary conditions. For patient RP results of correct responses revealed to be enhanced for condition I per semi-static and all frequency conditions, with peaks at 21 Hz and 38 Hz. For all values see Table 3.4.

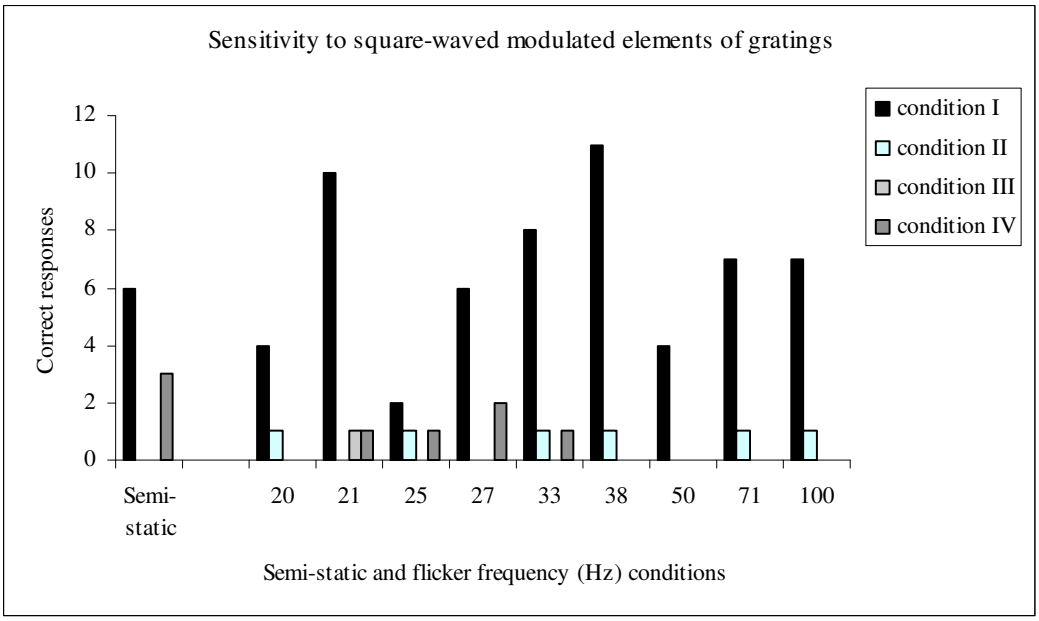



Figure 3.5: Patient RP: Bars denote frequency based correct responses for each condition (I, II, III and IV) per semi-static and frequency conditions. Correct responses were enhanced for condition I per semi-static and all frequency conditions, with peak at 38 Hz.

Table 3.4: Patient RP: Correct responses for each condition (I, II, III and IV) per semi-static and frequency conditions.

| Frequency (Hz) | Condition I | Condition II | Condition III | Condition IV |
|---|---|---|---|---|
| | Correct Responses | Correct Responses | Correct Responses | Correct Responses |
| Semi-static | 6 | 0 | 0 | 3 |
| 20 | 4 | 1 | 0 | 0 |
| 21 | 10 | 0 | 1 | 1 |
| 25 | 2 | 1 | 0 | 1 |
| 27 | 6 | 0 | 0 | 2 |
| 33 | 8 | 1 | 0 | 1 |
| 38 | 11 | 1 | 0 | 0 |
| 50 | 4 | 0 | 0 | 0 |
| 71 | 7 | 1 | 0 | 0 |
| 100 | 7 | 1 | 0 | 0 |

## Experiment 2:
## Discrimination of cosine-waved modulated gratings of different orientations

### Method

The method of Experiment 2 was the same than Experiment 1 with the following exceptions: in Experiment 2 stimulus presentation was enveloped within a cosine function: This is to say that the illumination of individual pixels was modified over intervals of 1 millisecond by the following function: cos(1-(t*2)/i), where t is time in milliseconds and i is the period of the stimulus frequency concerned. This ensured the removal of stimulus transients (aimed to reduce the extent to which attentional mechanisms might be encouraged during stimulus presentation) and produced a visibly different stimulus to that presented in Experiment 1. In this respect, the modulations were considerably less evident than with the square wave stimuli, even for relatively low frequency presentations. The changes in frequencies relative to Experiment 1 were due rounding errors arising through the conversion from integer to floating point representations in the program code.

The stimuli deployed in Experiment 2 appear simultaneously and repeatedly at one of nine frequencies (19, 21, 24, 27, 31, 38, 47, 62 and 90 Hz) or were presented as semi-static (i.e. did not flicker but were presented at the background plot rate of 1 kHz). The Experiment 2 consisted of 20 blocks of 40 trials each (in total 800 trials; consisted of 80 trials per frequency condition). The 20 blocks were separated by breaks, which lasted at least 10 seconds. A training block of 40 randomized practice trials was presented prior to the 20 experimental blocks. In total, the Experiment lasted for approximately 2 ½ to 3 ½ hours.

## Results

### Testing against chance performance

Analysis of probability of chance was the same than in Experiment 1: For each patient, responses of the 800 trials on which fixation was not maintained (FS: 2 trials, LE: 1 trial; no more than 1.25 % of trials per patient), were removed from the data prior to further analyses. There are no analysis of commentaries, as insufficient were given by any patient.

As illustrated in Figure 3.6 for patient RP and FS the percent correct responses for the different orientations per semi-static and frequency conditions lay in general within the confidence interval and therefore were not sufficiently different to chance performance. The percent correct response for patient RP, however, lay on the confidence interval and therefore was almost above chance for the frequency conditions 27 Hz (35 %). The percent correct responses for patient LE exceed the upper border of the confidence interval for semi-static [37.5 %] and all frequency conditions (19 Hz [47.5 %], 21 Hz [53.75 %], 24 Hz [37.5 %], 27 Hz [48.75 %], 31 Hz [47.5 %], 38 Hz [46.25 %], 47 Hz [51.25 %], 62 Hz [47.5 %] and 90 Hz [57.5 %]). For all values see Table 3.5.

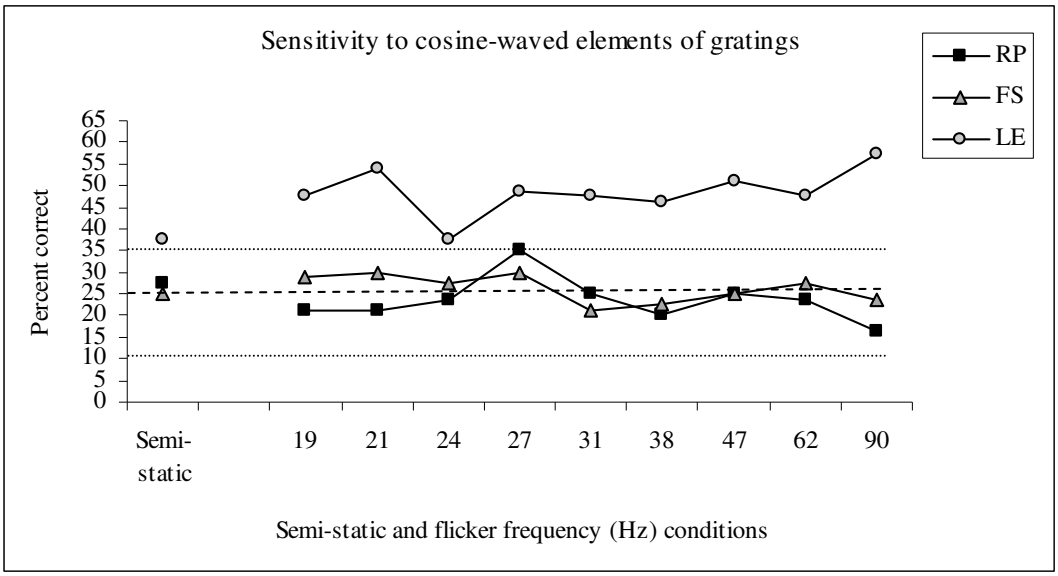



Figure 3.6: Patient RP, FS and LE: Function denotes percent correct responses for each orientation condition per semi-static and frequency condition, compared against assumed chance performance. The dashed horizontal line centred on .25 indicates the average response probability for each of 4 alternative responses. The flanking dotted lines represent the upper (99 %) and lower (1 %) confidence interval thresholds.. The trend shows to be almost the same for patient RP and FS. The trend for patient LE is different than to this of patient RP and FS. Patient LE performed significant better given semi-static and all frequency conditions (with peak at 21 Hz and 90 Hz).

Table 3.5: Patient RP, FS and LE: Values of percent correct responses for each orientation per semi-static and frequency conditions. Percent correct values significantly above chance are marked by * for $p < .01$.

| | RP | FS | LE |
|---|---|---|---|
| Frequency (Hz) | Percent correct | Percent correct | Percent correct |
| Semi-static | 27.5 | 25 | 37.5* |
| 19 | 21.25 | 28.75 | 47.5* |
| 21 | 21.25 | 30 | 53.75* |
| 24 | 23.75 | 27.5 | 37.5* |
| 27 | 35 | 30 | 48.75* |
| 31 | 25 | 21.25 | 47.5* |
| 38 | 20 | 22.5 | 46.25* |
| 47 | 25 | 25 | 51.25* |
| 62 | 23.75 | 27.5 | 47.5* |
| 90 | 16.25 | 23.75 | 57.5* |

Furthermore analysis of percent correct responses for each orientation condition by frequency were compared to the corresponding data given semi-static presentation, as the semi-static condition is the experimental control condition.

This is illustrated in Figure 3.7 where the bars denote the individually averaged response given semi-static condition. For patient RP the percent correct responses for all frequency conditions lay beneath her performance given semi-static presentation (27.5 %), with exception to slightly better performance at 27 Hz (35 %). Patient FS produced slightly better performance at all lower frequency conditions (19 Hz [28.75 %], 21 Hz [30 %], 24 Hz [27.5 %] and 27 Hz [30 %]) and following 62-Hz presentation (27.5 %), with performance at 47 Hz (25 %) equivalent to that following semi-static presentation (25 %). Patient LE showed a better performance at all frequency conditions (19 Hz [47.5 %], 21 Hz [53.75 %], 27 Hz [48.75 %], 31 Hz [47.5 %], 38 Hz [46.25 %], 47 Hz [51.25%], 62 Hz [47.5 %], 90 Hz [57.5 %]), with performance at 24 Hz (37.5 %) equalling that following semi-static presentation (37.5 %). Note that in his case, interpretation or comparison of frequency conditions against semi-static condition is illustrative, as the semi-static condition is also significantly better than model performance which reduces its utility as a control condition. For all values see Table 3.5.

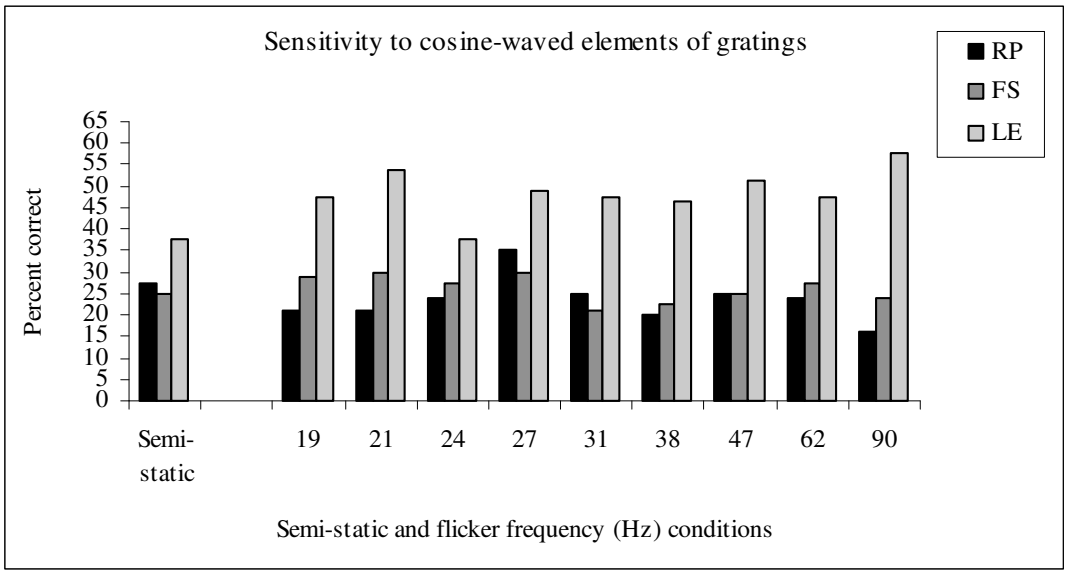



Figure 3.7: Patient RP, FS and LE: Bars denote percent correct responses for each orientation per frequency conditions, compared to the individually corresponding data given semi-static presentation. The trend is almost the same for the two cortically blind patients RP and FS, in contrast to the none-cortical blind patient LE. Patient LE performed better given all frequency conditions, in comparison to his performance at semi-static presentation, with one exception of 24 Hz and with peak at 21 Hz and 90 Hz.

Chi-square ($X^2$) Test

The analysis of ($X^2$) test was the same than in the classical blindsight experiment. For details of analyses see Chapter II (classical blindsight experiment).

The results revealed for patient RP and FS performances were not significantly different from chance performance given any presentation condition. Patient LE was significantly better than chance for all frequency conditions: (19 Hz = $X^2$ [3;99 %] = 22.8, $p < .01$; 21 Hz = $X^2$ [3;99 %] = 34.2, $p < .01$; 27 Hz = $X^2$ [3;99 %] = 23, $p < .01$; 31 Hz = $X^2$ [3;99 %] = 20.4, $p < .01$; 38 Hz = $X^2$ [3;99 %] = 18.6, $p < .01$; 47 Hz = $X^2$ [3;99 %] = 42.6, $p < .01$; 62 Hz = $X^2$ [3;99 %] = 22, $p < .01$; 90 Hz = $X^2$ [3;99 %] = 42.8, $p < .01$). For all values see Table 3.6.

Figure 3.8 illustrate that the performance of patients RP and FS do not differ much from each other and not much from the performance they produced given semi-

static presentation. Patient LE performed better following all frequency conditions in comparison to patient RP and FS and in comparison to the data he revealed given semi-static condition. This is in accordance with the results revealed for percent correct responses, with two exceptions for patient LE: the semi-static and frequency condition 24 Hz revealed to be significant in percent correct responses.

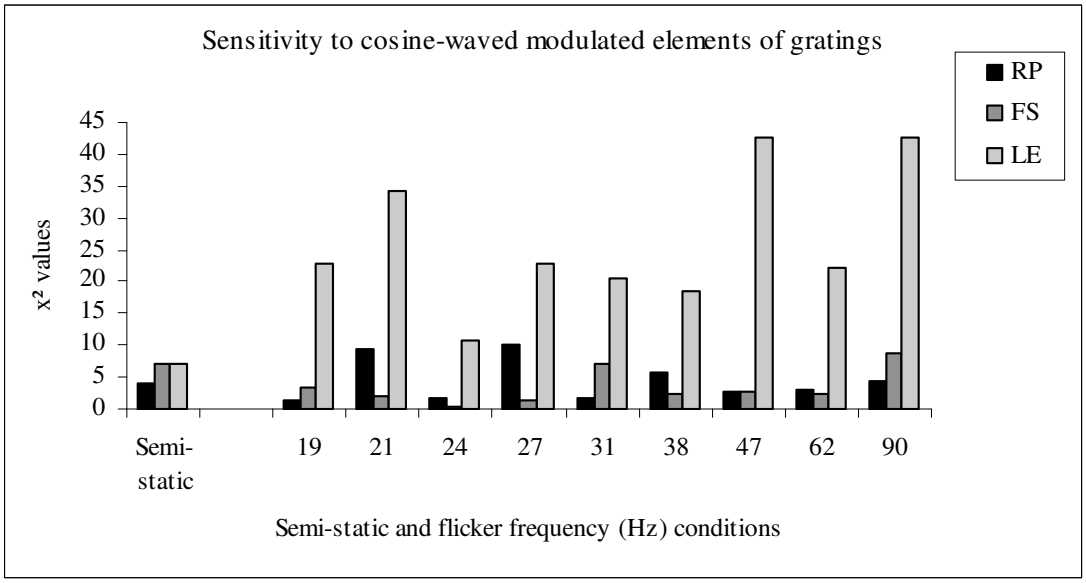



Figure 3.8: Patient RP, FS and LE: Bars denote $X^2$ values for each orientation condition per frequency and semi-static conditions. The trend is almost identical to the results of the percent correct responses, in respect to the performance of patient LE who performed different to the performances of the two cortically blind patients RP and FS and that these both performed for all frequencies almost the same than semi-static condition.

Table 3.6: Patient RP, FS and LE: Values of $X^2$ and significances (99 %, df 3, area = 11.34 and 95 %, df 3, area = 7.81) for each orientation condition per semi-static and frequency condition. $X^2$ values significantly above chance are marked by * for p < .01.

| | RP | | FS | | LE | |
|---|---|---|---|---|---|---|
| Frequency (Hz) | $X^2$ | $p$ = | $X^2$ | $p$ = | $X^2$ | $p$ = |
| Semi-static | 4 | | 7.2 | | 7.2 | |
| 19 | 1.4 | | 3.4 | | 22.8 | .0000* |
| 21 | 9.4 | | 2 | | 34.2 | 1.7974e-7* |
| 24 | 1.8 | | 0.4 | | 10.8 | |
| 27 | 10 | | 1.2 | | 23 | .0000* |
| 31 | 1.6 | | 7 | | 20.4 | .0001* |
| 38 | 5.6 | | 2.4 | | 18.6 | .0003* |
| 47 | 2.8 | | 2.8 | | 42.6 | 2.9253e-9* |
| 62 | 3 | | 2.4 | | 22 | .0000* |
| 90 | 4.2 | | 8.6 | | 42.8 | 2.6531e-9* |

## Discussion

The aim of the experiments and analyses described here was to examine whether the modulation of visual input at frequencies believed to be important for visual binding operations, enhances if not even mediates blindsight. Previous studies have shown that mechanism involved in binding operations in intact visual system is of temporal nature, thus patterns of synchronization can be assumed to be a general mechanism for perceptual organization and perhaps representation. In detail the aim of the current investigation was to examine the functionality of cortical mechanisms responsible for coding form-related structure in visual field defects. An enhanced discrimination of stimulus orientation in visual field defects was expected after presentation at frequencies in the gamma-band range (~ 20 - 80 Hz).

In order to explore these mechanisms a dynamical experimental approach was applied whereby, in Experiments 1 and 2, time varying visual stimuli was employed that

switched on and off in square-waves at 20, 21, 25, 27, 33, 38, 50, 71 and 100 Hz (Experiment 1) or were modulated periodically over time with a cosine-ramped luminance profile at 19, 21, 24, 27, 31, 38, 47, 62 and 90 Hz (Experiment 2).

For Experiment 1 percent correct responses were calculated and patients' performance was compared against a model of chance performance. The results revealed for patient RP that she did not perform significantly better than chance at any frequency, while FS was found to successfully discriminate the orientation of gratings only when they were presented at 38 Hz. For patient LE significantly better than chance performance was obtained given semi-static presentation and for almost all frequency conditions with peak performance at 20 Hz and 38 Hz. Patient-wise comparisons against performance under semi-static conditions (which was the experimental control conditions) revealed slightly better performance for patient RP only given 38-Hz flicker and for patient FS better following all frequencies, with best performance at 38 Hz. For patient LE, better performance was found for 20-Hz, 27-Hz, 33-Hz, 38-Hz and 100-Hz flicker. Note that in the case of LE, interpretation or comparison of performance relative to the semi-static condition is difficult because the semi-static condition produced significantly between performance in comparison with the model of chance performance (and thus its utility as a control comes under question in this case).

In a second step a $X^2$ analysis was employed to provide a bias free estimate of sensitivity given a tendency in all patients to preferentially respond using a limited subset of the 4 response alternatives. This analysis revealed significantly better than chance performance for patient FS when gratings were presented at 25 Hz, 38 Hz and 100 Hz and for patient LE at 20 Hz, 33 Hz and 38 Hz. Interestingly a similar trend was revealed for patient FS and LE who we both maximally sensitive to gratings flickering

at 33 Hz, 38 Hz and 100 Hz. In contrast patient RP performed best when gratings did not flicker. Even so, patient RP did show peak (if non significant) performance, in the analysis of percent correct data when the gratings were flickered at 38 Hz, a similar trend to that of the other two patients.

A further finding from Experiment 1 was that LE, who experiences non-cortical blindness, consistently achieved markedly better performance, irrespective to temporal modulation (and quite unlike either of the other two patients who suffer visual field defects due to cortical lesions). As is often the case in such non-cortical cases, several optic fibres survive the effects of damage and the blind area may be less dense than in the cortically blind patients, permitting some residual vision to occur. This is supported by the results, which revealed only in case of patient LE the same function for percent correct and $X^2$ analyses and by the results of the classical blindsight experiment, a study of discrimination ability in the absence of temporal modulation, which revealed for patient LE sensitivity to the presence of blank trials (in chi-square analysis), but no ability to discriminate the different orientations of the stimuli. This was in accordance with the performance of patient RP. In contrast to patient RP and LE, patient FS was neither able to discriminate between the different orientations, nor to discriminate between the presence and absence of a stimulus. One might ask, if patient RP and LE's ability to discriminate the absence and presence of stimuli indicate that some fibres survived and 'stray light' influence their performance thus absence trials set a criterion for their decision. However, this is neither an explanation for the ability of all patients to successful discriminate between the different orientations of the stimuli when temporal modulated as revealed in Experiment 1 nor that all patients have best performance in common when stimulated at 38 Hz. Furthermore it does not explain why patient RP was

able to comment on her decisions while patient LE was not. In relation to the commentaries patient RP gave it is of interest that most commentaries related to a 'brighter' (condition I) impression and that condition I was enhanced at 27 Hz and 100 Hz with peak at 21 Hz - but when commentaries were counted for correct responses the results revealed enhancements for condition I again at 21 Hz but this time with a peak at 38 Hz. In conclusion, RP showed best performances for form-discrimination and when correct, produced more comments when stimulated at 38 Hz. Furthermore as patient RP was not able to comment her decisions in the classical blindsight experiment one might claim a corresponding effect to that found by Trevethan and Sahraie (2003): namely that levels of awareness was higher under the experimental conditions for investigating temporal properties than in the additionally conducted examinations on spatial properties. Trevethan and Sahraie (2003) concluded that this as well may be attributed to the temporal content of the stimulus and here this notion is extended to show that it is specific to a given stimulus frequency, which interestingly has been implicated in the processes responsible for bringing perceptual material into awareness. However, this was not the case for the other two patients.

In general the patients in this study were able to discriminate form-related stimuli and tended to respond optimally at 38 Hz (and in case of patient LE at 20 Hz and 100 Hz). It can be concluded that temporally modulated gratings seem to encourage blindsight performance if presented at similar frequencies to those characterizing oscillatory synchronization during visual binding (von der Malsburg, 1981; Singer & Gray 1989 and 1995; Engel, König, Kreiter & Singer, 1991). As binding operations are assumed to be of temporal nature and blindsight is assumed to be based on visuo-cortical dysfunction attributable to some non-specific cortical lesion, it can be

concluded that alterations in the necessary state of equilibrium brought about by mass neuronal synchronization may be open to investigation by temporal (square-waved) modulation at gamma-band frequencies (similar to that shown by Elliott & Müller, 1998, 2000). What's more, the ability of patient RP to show visual awareness and better form-discrimination at 38 Hz might lead one to believe that these enhancements are related to a mechanism that temporarily binds the relevant neurons together by synchronizing their spikes in 40-Hz oscillations and thereby brings about visual awareness.

The results also support the idea of extrageniculostriate pathway mediating blindsight. This is because transient stimuli that include on and offsets enhance blindsight performance and the extrageniculostriate pathway consists of residual retinal cell axons (magnocellular cells), which are known to prove a high temporal frequency resolution and to generate transient responses in response to such stimuli. Furthermore the subcortical SC and V1 exhibit a similar retinopic representation of the visual field, whereas cells in these structures have receptive fields with antagonistic on- and off areas, although with no apparent functional specialisation. Concerning extrastriate activity it has been debated whether the P-pathway dominates the ventral and the M-pathway the dorsal pathway. Recently these projections are thought to be rather a mixture of different types of fibers. However, the results of external investigation of magnocellular cells by rapid on/off sets and discrimination task of different orientations suggest the M-pathway to dominate the dorsal pathway. This is of interest as usually dynamic shapes are associated with V3 of the ventral pathway and the ventral pathway is implicated in consciousness (Milner and Goodale, 1995, described in McGeorge, 1999). Note that this idea neither fits into findings of activation in V5 or prefrontal

cortices as found in blindsight II (Zeki & ffytche, 1998 and Sahraie et al., 1997), nor in the presence of visual awareness which was reported by patient RP, as this seems to be brought about by activity in the dorsal pathway. However, with respect to the aim of this study, and its results, it is difficult to clarify the question of which kind of fibers dominate the dorsal and ventral pathways and how these pathways are involved in visual awareness.

Concerning investigations with non transient stimuli, the cosine-waved stimuli provided a different pattern of effects to the square wave stimuli. For both cortically blind patients performance was not significantly better than chance (for patient RP almost at 27 Hz). Patient LE performed significant better given all frequency conditions (and in percent correct analysis additionally given semi-static condition) with peaks at 21 Hz and 90 Hz. Patient-wise comparisons against performance under semi-static conditions (which was the experimental control conditions) revealed better performance for patient RP only given 27 Hz flicker and for patient FS with slightly better performance following 19 Hz, 24 Hz and 62 Hz, and with equivalent and best performance following 21 Hz and 27 Hz. For patient LE significantly better performance was found for 19 Hz, 21 Hz, 27 Hz, 31 Hz, 38 Hz, 47 Hz, 62 Hz and 90 Hz with equivalent performance following 24 Hz presentation. Note that in the case of LE, interpretation or comparison of performance relative to the semi-static condition is difficult because the semi-static condition produced significantly between performance in comparison with the model of chance performance (and thus its utility as a control comes under question in this case).

Analysis of $X^2$ tests revealed no significant pattern of performance given semi-static and all frequency conditions for patient RP and FS. Patient LE performed significantly better than chance given all frequency conditions (except for 24 Hz) with peaks at 21 Hz, 47 Hz and 90 Hz. This is in accordance with the results revealed for percent correct data, with two exceptions: for patient LE the semi-static and 24 Hz were revealed to be significant in examination of the percent correct data.

However, as in Experiment 1 patients tend to discriminate the different orientations of the stimuli better when temporally modulated, but in contrast to Experiment 1, patients discriminate overall better at the lower frequencies: patient LE at 100 Hz, but as well at 21 Hz, patient FS at 21 Hz and 27 Hz and patient RP at 27 Hz. As in Experiment 1 both cortically blind patients showed the same function, again different to that of patient LE. The results of Experiment 2 could be interpreted as being based on the different strategies patients chose or basically on different kind of stimuli in Experiment 2. The stimuli in Experiment 2 were cosine-ramped giving a weaker signal and with a reduction in the extent to which attentional mechanisms might be encouraged to respond to stimulus presentation. In this respect their effects might be expected to be considerably less evident than the effects of square wave presentation, even for relatively low frequency presentations. This also might be one reason for the absence of commentaries for all patients in Experiment 2. Nevertheless it should be mentioned that patient LE performed best at 20 Hz in Experiment 1 and all patients performed well at the lower frequencies in Experiment 2. This fits into findings by e.g. Trevethan and Sahraie (2003) of better discrimination of sinusoidal modulated gratings within a narrow range of frequencies between 10 and 33 Hz (with sensitivity peak at 20 Hz).

Although there are differences between Experiment 1 and 2 the two cortically blind patients RP and FS performed similar and in contrast to patient LE. Differences in patients' sensitivity could be due to the different lesions they suffered, the age of the lesions and the different ages of patients when suffering cerebral insult. In general it is difficult to find a similar sample of patients because of a number of reasons: Firstly it is difficult to find patients showing blindsight as usually blindsight performance is not tested in hospitals. Secondly testing of patients with visual field defects to examine blindsight phenomena would not profitable more than ever patients with blindsight phenomena are known to show performances on individually different, stimulus-specific configurations. Thirdly patients with blindsight do not profit –obviously- from being blindsighters; this makes it difficult for researcher to find patients with visual field defects to participate at experiments.

Nevertheless and in conclusion, in both experiments, three different patients showed visual experiences, which were significantly enhanced when stimuli were temporally modulated in the gamma-band range. It can be concluded that form-based processing seems to be influenced at frequencies which are implicated in binding-by-synchronisation in and with visual cortex. External temporal modulation (Elliott & Müller, 1998) can be used to investigate impaired internal synchronisation and alterations in the state of equilibrium of visuo-cortical function ordinarily brought about by virtue of dynamic binding. In this respect and as a start, the conclusion can be drawn that impaired input from V1 is compensated for by enhanced higher-order processing and that this compensation is responsible for residual visual capacities in the impaired field, thus temporal influences mediate blindsight phenomena.

# CHAPTER IV:
# The effects of flicker on detection performance in blindsight

## Introduction and Review

Based upon the evidence elaborated in the introductory chapters and previous experiments (for details see Chapter I and III) one can regard the visual system as being temporal in its basic characteristic and temporally modulated stimuli can be expected to influence blindsight capability. Consequently, a general enhancement of response accuracy following temporally modulated (by means of square wave or cosine wave) stimuli in contrast to static stimuli is assumed. What's more is the relation to a question Weiskrantz (1986) already put: this is whether blindsight is qualitatively similar to normal vision-being merely degraded in its capacity- or whether there are qualitative differences in kind. Answering this question should be achievable by comparing measures of detection and form discrimination in the intact and blind fields. What he found was a double dissociation concerning signal detection and form discrimination in the intact and blind hemifield. Form discrimination capacity was better in the intact field as one would expect. However in contrast, signal detection (sensitivity for a spot detection task) capability was found to be better in the blind area. Based upon findings of residual visual capacities to be at least partially intact during light detection (e.g. Weiskrantz, Warrington, Sanders & Marshall, 1974) detection of a visual discontinuity in visual field defects can be expected to be enhanced by stimulus presentation at frequencies in the gamma-band range (~ 20 - 80 Hz) and which have been shown to be of interest in Experiments 1 and to a lesser extent 2.

## Experiment 3:

## Detection of square-wave modulated continuous or discontinuous gratings

### Method

For details of participating patients, additionally examinations as well as methods see Chapter II (classical blindsight experiment). For the results of visual field perimetry see Chapter III (Experiment 1).

#### Design and procedure

The design and procedure of Experiment 3 were the same than Experiment 1 (see Chapter III) with the following exceptions:

Experiment 3 differed from Experiment 1, in that Experiment 3 was a detection task, which consisted of four response alternatives, requiring confidence estimates (continuous certain, continuous uncertain, discontinuous certain and discontinuous uncertain) and patients were asked to judge, which of the three different stimuli was presented (continuous or discontinuous gratings) giving the confidence appraisal with their judgement. Experiment 3 consisted of 11 blocks of 40 trials each (in total 440 trials; consisted of approximately 58 trials per frequency condition). In total, the experiment lasted for between 1½ to 2½ hours.

Apparatus and stimuli

The apparatus and stimuli of Experiment 3 were the same than Experiment 1 (for details see Chapter III) with the following exceptions:

Experiment 3 differed from Experiment 1, in that stimuli covered an area of 2.3° x 0.9° of visual angle in case of the continuous stimuli and an area of 2.3° x 1.0° of visual angle in case of the discontinuous stimuli. As is illustrated in Figure 4.1, the stimulus could appear as continuous stimuli and as two different kinds of discontinuous stimuli (two bisections).

Figure 4.1: The three parallel bar gratings.
(a) shows the continuous stimulus, (b) one discontinuous stimulus and (c) the other discontinuous stimuli.

The stimuli deployed in Experiment 3 consisted of a square-wave modulated grating of three parallel bars (physical properties of the bars are described in Experiment 1). The grating appear simultaneously and repeatedly at one of seven frequencies (25, 27, 33, 38, 50, 71 and 100 Hz) or were presented as semi-static (i.e. did not flicker but were presented at the background plot rate of 1 kHz).

## Results

### Signal detection

For all frequency conditions, the signal detection sensitivity parameter $A_z$ was derived from the judgments, using the maximum-likelihood (ML) estimation procedure for rating method data developed by Dorfman and Alf (1969)[1]. The $A_z$ value is an estimate of the area under the Receiver Operating Characteristic (ROC) curve, based on the maximum likelihood fit of the curvilinear function through the points of the empirical ROC curve. An area of .5 would represent a case of an inability to discriminate, whereas an area of 1 would indicate a perfect discrimination. If the area under an ROC curve covers 75 % (i.e., the value of $A_z$ is .75) then discrimination can be assumed to differ substantially from chance performance[2]. For all patients, the average $A_z$ values for hits and false alarms were tested against random-guessing level ($A_z$ = .5), by calculating the lower and upper threshold of a 99% confidence interval.

[1] Every stimulus condition has a certain likelihood ratio l(x) which functions as a cut-off point or criterion for the patients to decide whether a particular observation, x, is above or below the criterion. In signal detection theory (SDT) a likelihood ratio is the ratio of the ordinate of SN (signal-plus-noise distribution) and the ordinate of N (noise distribution). It is used by observers as a criterion to decide if a certain sensory observation x results from a condition in which a signal is present, accompanied by a certain noise, or from a noise only condition. In this case l(x) determines the decision which signal present [orientation] or signal absent [blank] condition is observed.

[2] The term ROC, Receiver-Operating Characteristic, comes from the signal detection theory (SDT; for details see Gescheider, 1985). The calculation of an ROC curve is a means to simultaneously investigate specificity and sensitivity independently from the base rate for different test criteria. The term sensitivity stands for the hit rate (i.e. the probability to respond for a signal, when signal is present) = signal + noise. Specificity stands for 1-false alarm rate (i.e. the probability to respond for a signal, when signal is absent) = noise only. Each pair of hit and false alarm proportions within one category provides a point for the ROC curve.

This is illustrated in Figure 4.2 where the dashed horizontal line centred chance level on .05. Using this procedure it was revealed that none of the patients RP, FS and LE performed with significant difference from chance. One important finding was that semi-static performance was not necessarily at or close to chance in all patients and therefore its utility as a control condition is reduced. For all values see Table 4.1.

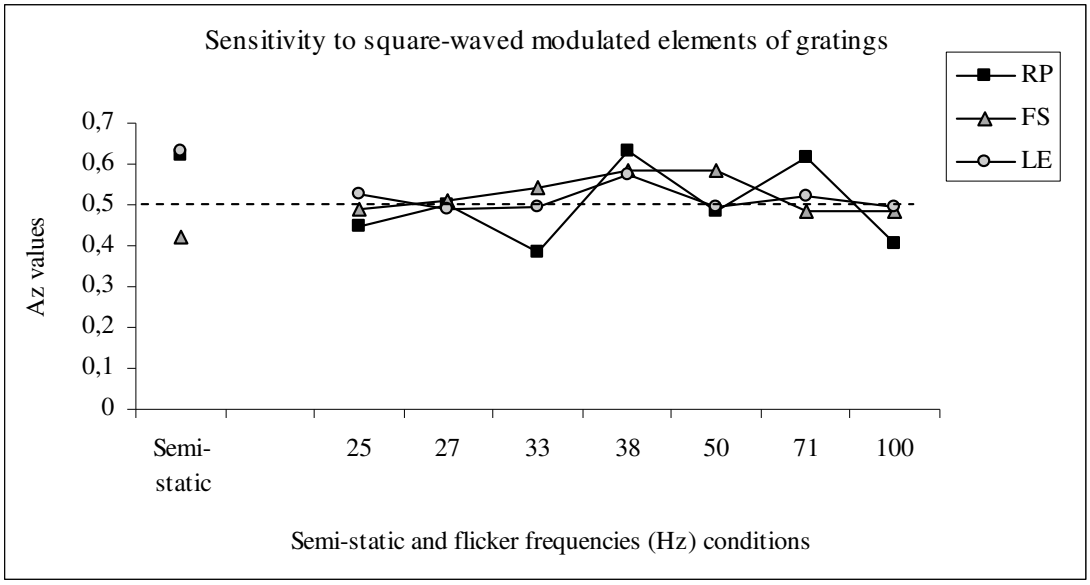



Figure 4.2: Patient RP, FS and LE: Function denotes $A_z$ values for each continuous and discontinuous condition per semi-static and frequency condition. The dashed horizontal line centred on .05 indicates the random-guessing level. None of the patients RP, FS and LE performed significantly better or worse than chance performance. The trend shows that all patients RP, FS and LE performed better than chance at 38 Hz (with exceptions in the data of patient FS at 50 Hz and of patient RP at 33 Hz and 71 Hz).

Table 4.1: Patient RP, FS and LE: Values of $A_z$ and SE mean (Standard Error of Mean) for each continuous and discontinuous condition per semi-static and frequency condition. Bonferroni correction for multiple comparisons was applied.

| | RP | | FS | | LE | |
|---|---|---|---|---|---|---|
| Frequency ( Hz) | $A_z$ | SE mean | $A_z$ | SE mean | $A_z$ | SE mean |
| Semi-static | .6206 | .0631 | .4198 | .0606 | .6328 | .0672 |
| 25 | .4474 | .0619 | .491 | .0594 | .5272 | .0658 |
| 27 | .4976 | .0625 | .5117 | .06070 | .4904 | .06410 |
| 33 | .3837 | .0648 | .5427 | .06250 | .4948 | .06930 |
| 38 | .6301 | .068 | .582 | .05900 | .5732 | .06650 |
| 50 | .4844 | .0653 | .5867 | .0615 | .4925 | .0652 |
| 71 | .6174 | .0654 | .4826 | .0638 | .5233 | .0656 |
| 100 | .4041 | .067 | .484 | .0651 | .496 | .0655 |

## Experiment 4:

## Detection of cosine-wave modulated continuous or discontinuous gratings

### Method

The method of Experiment 4 was the same than Experiment 3 with the following exceptions: Experiment 4 differed from Experiment 3, in that stimulus presentation was enveloped within a cosine function as described for Experiment 2 (see Chapter III).

The stimuli deployed in Experiment 4 appear simultaneously and repeatedly at one of seven frequencies (24, 27, 31, 38, 47, 62 and 90 Hz) flickering conditions or were presented as semi-static (i.e. did not flicker but were presented at the background plot rate of 1 kHz). Experiment 4 consisted of 12 blocks of 40 trials each (in total 480 trials; consisted of 60 trials per frequency condition). The 12 blocks were separated by breaks, which lasted at least 10 seconds. The experimenter, who remained with the patient during the entire experiment, initiated each new block as soon as the patient was

ready to resume testing. A training block of 40 randomized practice trials was presented prior to the 12 experimental blocks. In total, the experiment lasted for between 1½ to 2½ hours.

## Results

### Signal detection

Analysis of signal detection was the same than in Experiment 3. As illustrated in Figure 4.3 results revealed that none of the patients RP, FS and LE performed with significant difference from chance. For patient FS and LE semi-static performance was not at or close to chance and therefore its utility as a control condition is reduced. This is in contrast to patient RP performance at semi-static condition, which was at chance. For all values see Table 4.2.

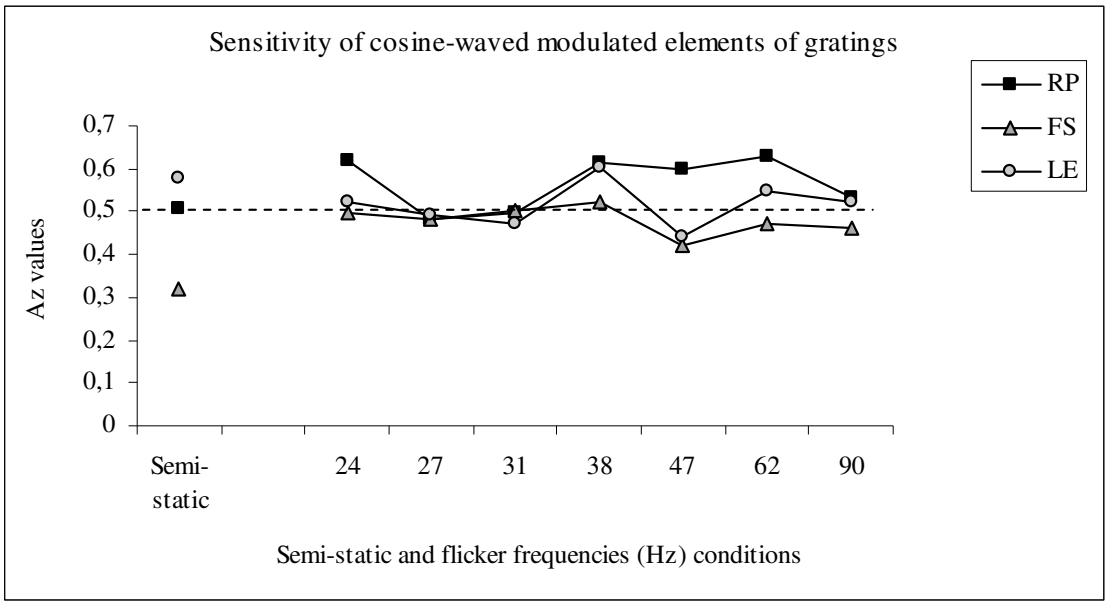



Figure 4.3: Patient RP, FS and LE: Function denotes $A_z$ values for each continuous and discontinuous condition per semi-static and frequency condition. The dashed horizontal line centred on .05 indicates the random-guessing level. None of the patients RP, FS and LE performed with significant difference from chance. The trend shows that patient RP and LE performed better than chance at 38 Hz (with exceptions in the data of patient RP at 24 Hz, 47 and 62 Hz).

Table 4.2: Patient RP, FS and LE: Values of $A_z$ and SE mean for each continuous and discontinuous condition per semi-static and frequency condition.

| | RP | | FS | | LE | |
|---|---|---|---|---|---|---|
| Frequency ( Hz) | $A_z$ | SE mean | $A_z$ | SE mean | $A_z$ | SE mean |
| Semi-static | .5085 | .0647 | .3197 | .0555 | .5798 | .0581 |
| 24 | .6197 | .0576 | .4955 | .059 | .5249 | .058 |
| 27 | .481 | .0589 | .4807 | .059 | .4923 | .058 |
| 31 | .4964 | .062 | .50110 | .0586 | .46960 | .0598 |
| 38 | .6148 | .0584 | .52350 | .0593 | .60350 | .0572 |
| 47 | .5974 | .0647 | .41990 | .0584 | .44160 | .0595 |
| 62 | .6297 | .0576 | .4727 | .0586 | .5462 | .0591 |
| 90 | .5336 | .0591 | .4612 | .0583 | .5224 | .0584 |

## Discussion

The aim of the current investigation was based on the same assumption as those in Experiment 1 and 2 (see Chapter III) in which the functionality of cortical mechanisms responsible for coding form-related structure in visual field defects were examined. Assuming Blindsight performance to be influenced by a temporal modification of presented stimuli, an entrained frequency response with a frequency bandwidth may be important for visuo-perceptual organisation. An enhanced detection of a visual discontinuity in visual field defects by stimulus presentation was expected at frequencies in the gamma-band range (~ 20 - 80 Hz). In Experiment 3 and 4 visual hyper-acuity (the ability to detect a discontinuity in the blind field), was investigated by using square-wave (25, 27, 33, 38, 50, 71 and 100 Hz) and cosine-waved (24, 27, 31, 38, 47, 62 and 90 Hz) modulation of continuous and discontinuous gratings.

In Experiment 3 signal detection analysis revealed discrimination performance was no better than chance for any of the participating patients. Comparisons against performance under semi-static conditions (which was the experimental control conditions) revealed slightly better performance for patient RP only given 38-Hz flicker (and almost at 71 Hz) and for patient FS better following all frequencies, with best performance at 38 Hz and peak at 50 Hz. Comparison against performance following semi-static presentation was very similar for patients RP and FS to that found in Experiment 1 (with one exception in the data of patient FS at 50 Hz). Comparison against performance following semi-static conditions revealed worse detection for temporally modulated stimuli than for the semi-static condition for patient LE.

This is in contrast to Experiment 1, where he could discriminate stimuli better when they flickered. In Experiment 1 it was assumed that in case of patient LE and as is

often the case with patients experiencing non-cortically located visual field defects, several optic nerve fibres may have survived the insult and the blind area may be less dense than in the cortically blind patients, thus permitting some residual vision to occur. However and besides comparison to performance following semi-static condition, Experiment 1 revealed the same trend in chi-square analysis for patient FS and LE given frequency conditions at 33 Hz and 38 Hz (and almost the same at 27 Hz). This is in accordance with Experiment 3 where almost the same trend for patients FS and LE was observed who both reported at around chance level. Based upon these data one might conjecture LE's performance to not attributable to some straightforward factor such as the presence of surviving fibres because he reveals the same trend as cortically blind FS with performance that was not consistent across the two discrimination tasks undertaken in Experiments 1 and 3. In Experiment 3, as in Experiment 1, there was a (non significant) trend for slightly enhanced sensitivity to stimuli at 38 Hz (with two exceptions of additionally better detection in the case of patient RP at 71 Hz and patient FS at 50 Hz), even if performance at 38 Hz does not reach or exceed performance given semi-static presentation (as in the case of patient LE). This is in accordance with findings in Experiment 1, where patients discriminated stimuli better given presentation at 38 Hz (even if patient RP revealed to perform significantly at semi-static condition when analysed with chi-square test) and in case of patient RP correct responses were associated with substantially more comments at 38 Hz than at other frequencies. Interestingly and in comparison to Experiment 1, all patients were found to be better in discriminating than detecting stimuli (in case of patient RP only better than semi-static condition when stimulated at 38 Hz). The differences between the discrimination and detection tasks might be due to the different stimuli configurations which were

presented in the experiments or might be based on the task, in particular, on what they were asked to do.

Concerning investigation with none-transient stimuli in Experiment 4, signal detection analysis revealed none of the participating patients to report with significantly better than chance performance and this was true for both comparisons against chance performance and against semi-static control presentations. In these comparisons there is a tendency for patient RP to detect stimuli better at 24 Hz, 38 Hz, 47 Hz and 62 Hz. Patient FS performed around chancel level given all frequencies (except of 47 Hz were he detected stimuli with worse than chance performance reflecting, perhaps an incorrect response bias) and better given all frequency conditions in comparison to semi-static presentation. For patient LE detection performance was again found to be worse given all frequency conditions in comparison to semi-static presentation, with exception to slightly better performance following presentation at 38 Hz.

In conclusion, only patient RP (who differs from patient FS and LE) performed similar to Experiment 1 with respect to her sensitivity and her comments. In her case, external temporal stimulation leads to a different performance. Nevertheless, for all patients' discrimination performance was better than detection performance and, in case of cosine-waved modulated stimulation, different to Experiment 2 and 4. One can conclude that for some reason fine scaled or detailed form-based analysis is not supported in blindsight, this may be due to the fact that blindsight supports only very coarse-scaled form discrimination: given the right conditions detecting a large-scale orientation cue is achievable, but detecting a small-scale discontinuity simply requires

more localized visuo-cortical mechanisms, which are much less likely to survive a lesion or be augmented by activity in ancillary visual pathways. This suggests an extrastriate locus for the effects obtained in Experiments 1 and 2 (especially in Experiment 1), which possibly lays in form-from-motion coding mechanisms in V3 or V5.

# CHAPTER V:
# Temporal stimulation of transition zone

## Introduction and Review

Given temporal stimulation and given blindsight performance for key stimulus frequencies it is not unreasonable to expect a translation from relative blindness to visual function close to the border of the intact, relative and absolute blind fields, referred to as the transition zone. This idea is based on previous studies showing that performance of trained humans performing detection tasks and using information just inside the transition zone has lead to some good indications that the morphology of the visual field defect can constrict with training and that a lesion in the central visual system does not always result in a complete and permanent loss of function (Zihl & von Cramon 1979 and 1985). Training methods such as VRT (reported in sensational series of reports by Sabel and colleagues - for original report about VRT see Kasten & Sabel, 1995) support this idea (Kasten, Wüst, Behrens-Baumann & Sabel, 1998; Kasten, Poggel & Sabel, 2000; Wüst, Kasten & Sabel, 2004). For example Kasten, Poggel, Muller-Oehring, Gothe, Schulte and Sabel (1999) have reported that following VRT transition zones can shift for up to about 5° of visual angle and that more than ¾ of patients report subjective improvements in visual performance. On the other hand, training methods like VRT has been doubt for several reasons. Horton (2005) assumes that successful training is in reality just due to procedural artefacts such as an inability of maintain fixation and to keep the training stimuli in the blind field. He goes on to state that training programmes reported to be effective for both monocular optic nerve diseases and homonymous, post-chiasmatic

lesions are questionable, as there is no '…physiological mechanism that could explain improvement from the same treatments at different levels of the visual system' (Horton, 2005, p.1). Additionally there is no evidence that visual cortex of an adult is trainable in contrast to, for example, the learning of new motor skills (achieved by patients with partial paralysis by e.g. a stroke). This is possible due to still functional muscle groups and cannot be considered equivalent to or comparable with the action of surviving neurons. In support of this point of view, Horton refers to Balliet, Blood and Bach-y-Rita (1985), who examined patients (homonymous hemianopic or quadrantanopic) with similar methods, but in which possible contaminating experimental variables were controlled for. In their study the morphology of the visual field did not change.

To evaluate the prediction of a modification of defect morphology, the visual field morphologies were examined using static visual field perimetry prior to and after patients underwent a number of sessions of stimulation using a matrix of illuminated pixels presented at various frequencies (in square-wave and in case of RP additionally cosine-wave forms) to which patients had revealed some blindsight sensitivity in previous experiments (see Chapter III).

## Experiment 5:
## Temporal stimulation of individually transition zone in static visual field perimetry

### Method

In a first step a static visual field perimetry was conducted prior to of Experiment 5 and for each patient and each eye separately (OS[1] and OD[2]). Based on the results of the static visual field perimetry the visual field deficits and on an individual basis the area of the transition zone of each participating patient were examined. This static visual field perimetry thus represented the pre-treatment measure, referred to as the 'baseline condition'. Note that as Experiment 5 required considerable time and effort on the part of the patients, baselines were calculated and Experiment 5 was conducted, proper, on different days. In a second step Experiment 5 was conducted by means of the temporal and semi-static stimulation of specific areas within the transition zone. These areas were decided upon on the strength of the morphology of the visual field for each patient individually. Following stimulation, patients were asked to immediately undergo a further static visual field perimetry measure, referred to as the 'post-treatment measure'. The effectiveness of stimulation in reducing the size of the defect fields or enhancing the size of the intact fields was then assessed by comparing baseline condition and post-treatment measures. As there were three temporal stimulation conditions (frequencies used were revealed to improve better performances in previous experiments) and one semi-static stimulation, each patient underwent four sessions and four corresponding post-treatment measures of static visual field perimetry. The sequence of each stimulation and static

[1] OS (Oculus sinsister) = left eye

[2] OD (Oculus dexter) = right eye

visual field perimetry measures were conducted in one session, in the same room and at the same day for each patient. The aim of Experiment 5 was thus to assess changes of the morphology of the visual field as revealed by post-treatment measures by calculating the degrees squared of visual angle ($°^2$) of the intact, relative blind and absolute blind fields separately within the individually area of transition zone and comparing those measures with the measures calculated baseline condition.

Method of static visual field perimetry and participating patients

For details of participating patients see Chapter II (classical blindsight experiment). The method of Experiment 5 was the same than in the classical blindsight experiment with the following exceptions: Experiment 5 differed from the classical blindsight experiment, in that patient FS was conducted by the same visual field perimetry system as the patient RP and LE (in his case the fixation point was a white point-mark, while for the others it was a green cross-hair) and that for all three patients both eyes (OS and OD, starting with OS) were conducted. A break between the measures of each eye could be as long as patients wished to have it. Each static visual field perimetry measures lasted for approximately 45 minutes, in total. Each patient was paid € 100.00 (Euro) per day plus travel expenses.

Results of static visual field perimetry and deficits of participating patients

The results of the visual field measure for each patient are illustrated in Figure 5.I (a-f). Here the rectangles represent 2° squared of visual angle (°²). The white rectangles signify the intact fields (i.e. fully functional) visual field(s), the grey signify the relative blind and the black rectangles signify the absolute blind field(s.).

The female patient (RP) has an upper right homonymous quadrantanopia, which overlaps into the lower right quadrant. This is in accordance with the damage, caused by a stroke**,** in the left occipital cortex, when she was at the age of 54. Macular sparing of 18.25°² of visual angle (OS) and 12.25°² of visual angle (OD) to the upper right quadrant from fixation point is evident**.**

The first male patient (FS) has a right homonymous hemianopia, with additional relative defects in the upper and lower left part of the visual field, without macular sparing. This is in accordance with the damage of the left hemisphere, caused as a result of a head injury form a road accident (which lead to a severe craniocerebral trauma), when he was at the age of 42. For MRI, see Appendix, Chapter II, Image 1.

The second male patient (LE) suffers from a non-cortical blindness. In his case surgery was conducted to remove a tumour located under the left optic nerve, when he was at the age of 46. In comparison to previous studies static visual field perimetry revealed for patient LE a complete blindness for OS; for OD static visual field perimetry revealed some absolute and relative blind fields in the upper right and left quadrant**,** without macular sparing (there are no further details about his lesions, as patient LE is just clarifying the state of tumour and lesions). For MRI, see Appendix, Chapter II, Image 2.

## Method of Experiment 5

### Design and Procedure

As Experiment 5 required considerable time and effort on the part of the patients, the baseline condition and Experiment 5 were conducted on different days. Experiment 5 (a) was conducted 19 days after the baseline condition for patient RP, 17 days after the baseline condition for patient FS and again 19 days after the baseline condition measure for patient LE. Experiment 5 (a) started when patients were sitting in front of the oscilloscope. They were instructed to avoid eye-movements and to maintain fixation on the coloured fixation point. Each stimulation epoch lasted for four minutes and was presented on three occasions, successively, with a break of at least 10 seconds between epochs. The investigator, who remained with the patient during the entire experiment, initiated each new epoch when the patient was ready to resume testing. Although all patients were well used to participate in similar experiments, sometimes for longer periods, there may have been problems in maintaining vigilance. This consideration precipitated the division of stimulation into three successive blocks or epochs and in addition, a horizontal target bar was presented within each epoch and patients were asked to maintain vigilance and to respond in a filler task, to the appearance of the target bar, which could occur at any spatial location. Detection performance was not analysed as the aim of Experiment 5 was to stimulate within the transition zone. Each patient underwent stimulation with three frequencies and semi-static and these 12 minute sessions were conducted entirely separately. The order of presentation of the three frequencies investigated was counterbalanced across patients to avoid order effects. As shown in Table 5.1 all patients started with semi-static presentation, such that each frequency was

presented once after the semi-static stimulation and once at each possible sequence position. The choice of frequencies was based upon those frequencies at which patients showed enhanced blindsight performance in Experiments 1 or 2, at which changes in the morphology of the visual field might be expected. Other frequencies were those at which they might not be expected to experience blindsight and for these frequencies no changes in visual field morphology was expected.

Table 5.1: Patient RP, FS and LE: The order of the semi-static and flicker frequency stimulations.

| RP | FS | LE |
|---|---|---|
| Frequency (Hz) | Frequency (Hz) | Frequency (Hz) |
| 0 | 0 | 0 |
| 27 | 20 | 38 |
| 38 | 27 | 20 |
| 20 | 38 | 27 |

In total the Experiment 5 (a) lasted for approximately eight hours per patient. There was a 10 to 15 minutes break following each of the stimulations as well as in-between and following each post-treatment measures of static visual field perimetry, except of a longer 30 to 45 minutes break for patient RP and FS after the 27-Hz stimulation and for patient LE after the 20 Hz.

Apparatus and Stimuli

The apparatus and stimuli of Experiment 5 were the same than Experiment 1 (for details see Chapter III) with the following exceptions:

Experiment 5 differed from Experiment 1, in that Experiment 5 was performed in a dimly lit room under controlled lighting conditions (mean screen surround luminance of 0.011 cd/$m^{-2}$, with stimulus luminance maintained at 2.5 cd/$m^{-2}$). As illustrated in Figure 5.1, the stimuli were a 3 x 3 square matrix of nine dots in horizontal and eight dots in vertical line per square (72 dots per square, in total 648 dots per stimulus). The stimuli covered an area of $8°^2$ of visual angle. To help patients to maintain vigilance a target bar was presented within the 3 x 3 matrix. The target bar was of length 0.61° of visual angle and appeared with a probability of .25 within each 30 sec. of stimulus presentation. If presented, the bar remained onscreen for 1000 ms. The spatial location of the bar was randomised within each block and not recorded.

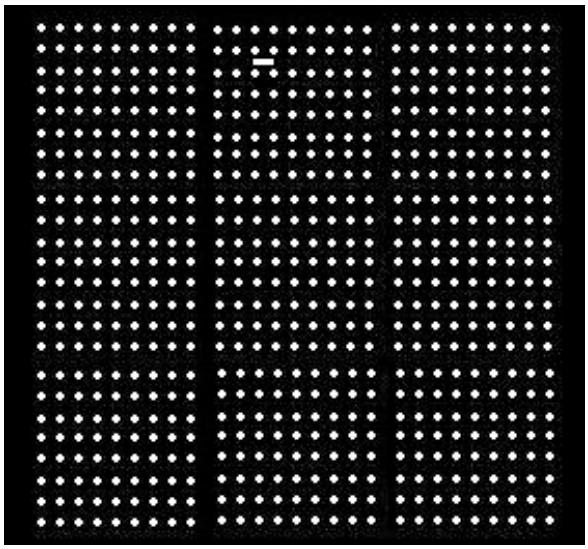
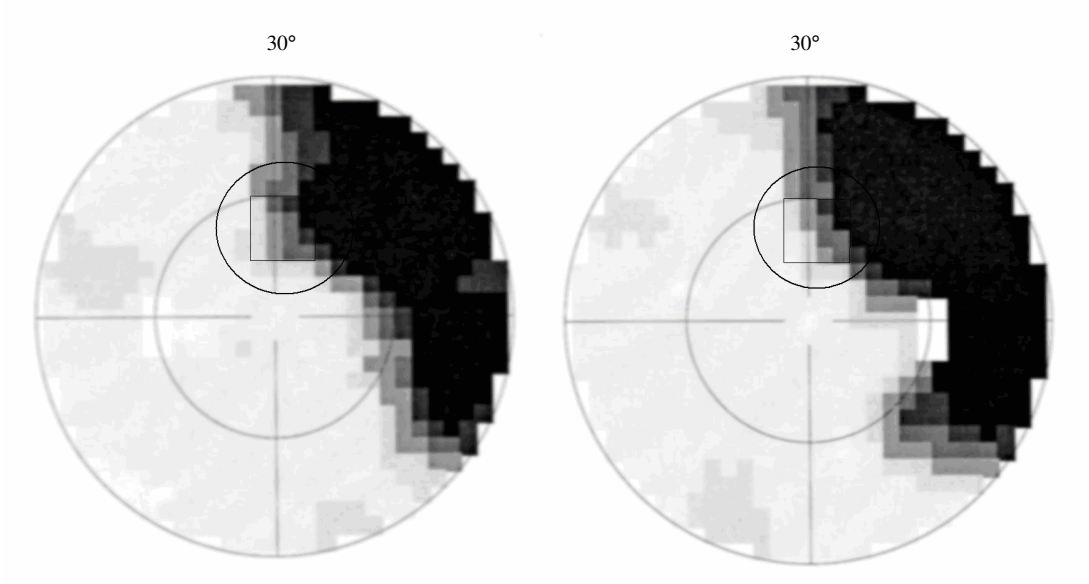


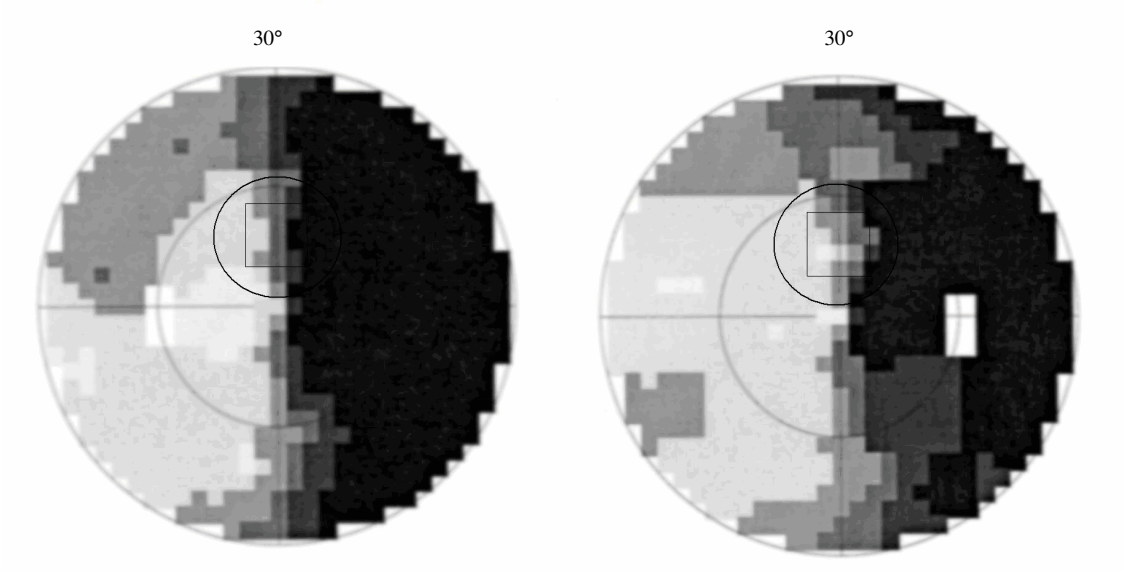
Figure 5.1: The 3 x 3 square matrix of nine dots in horizontal and eight dots in vertical line per square (72 dots per square, in total 648 dots per stimulus). The horizontal bar in the middle square of the first row is an example of a target, which could appear at a random location within the matrix.

In Experiment 5 the illuminated pixels were presented in-phase and periodically in square-waves at one of three frequencies (20 Hz, 27 Hz, and 38 Hz) flickering conditions or were presented as semi-static (i.e. did not flicker but were presented at the background plot rate of 1 kHz). The stimuli were not equivalent to Gaussian-weighted increase and decrease in image luminance. Based upon the results of the baseline condition, the position of a fixation point was calculated for each patient enabling the stimuli to be presented in the individually part of the transition zone.

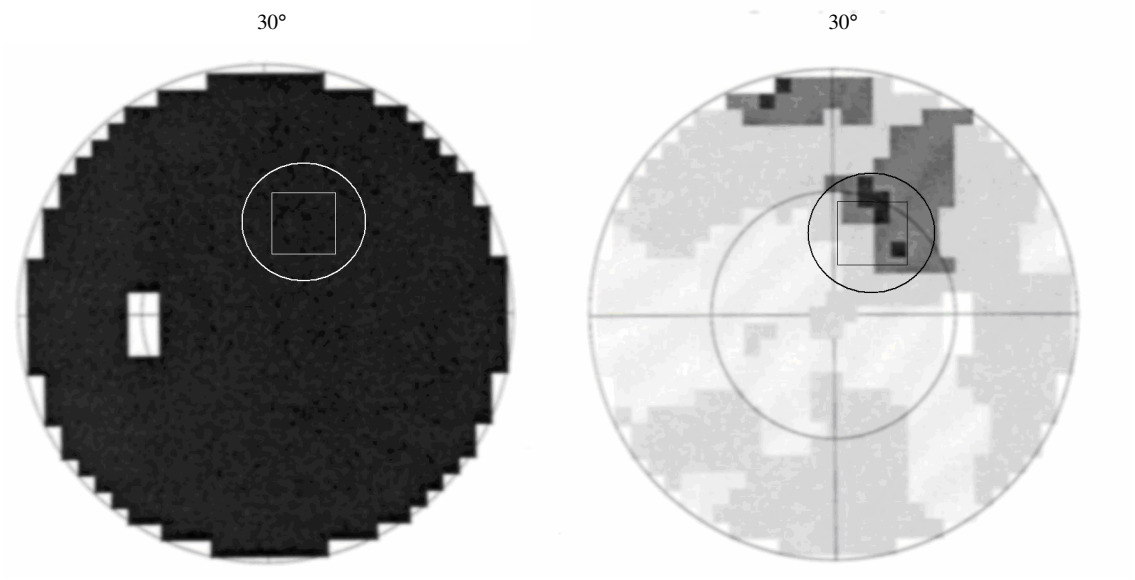
As illustrated in Figure 5.I (a-f) the exact positions of the middle of the stimuli were for patient RP on x (axis of abscissa) = + 1°² of visual angle and on y (axis of ordinates) = + 7°² of visual angle, for patient FS on x = 0°² of visual angle and on y = + 5°² of visual angle (in Experiment 5 (b) on x = + 1°² of visual angle and on y = +5°² of visual angle) and for patient LE x = + 4.5°² of visual angle and on y = + 6.5°² of visual angle, within the central 15° region of the visual field (for the results in an overview see next page).




(a): RP (OS) baseline condition (b): RP (OD)




(c): FS (OS) baseline condition (d): FS (OD)




(e): LE (OS) baseline condition (f): LE (OD)

Figure 5.I: The results of the static visual field measure for (a) OS and (b) OD for patients RP, FS and LE, referred to as the baseline or pre-treatment condition. Each rectangle represents 2°² of visual angle. The white rectangles signify the intact fields (i.e. fully functional) visual field(s), the grey signify the relative blind and the black rectangles signify the absolute blind field(s.). The white vertical rectangle symbolised the blind spot. Based on these baseline conditions the individually area of the transition zone, with size of 8° x 8° of visual angle was calculated. Total size of the static visual field perimetry was 30°² of visual angle. The transition zone was within the 15°² of visual angle area of the 30°² of visual angle (indicated by the black circle). The stimuli are indicated by a black rectangle in a white or black circle.
(a) and (b) patient RP has an upper right homonymous quadrantanopia, which overlaps into the lower right quadrant. Macular sparing of 18.25°² of visual angle (OS) and 12.25°² of visual angle (OD) to the right upper quadrant from fixation point is evident. (c) and (d) patient FS has a right homonymous hemianopia, with additional relative defects in the upper and lower left part of the visual field; without considerable macular sparing. (e) and (f) patient LE suffers from a non-cortical blindness. He is complete blind on OS; for (OD) static visual field perimetry revealed some absolute and relative blind fields in the right upper quadrant and in the left/ middle upper quadrant; without macular sparing.

## Results

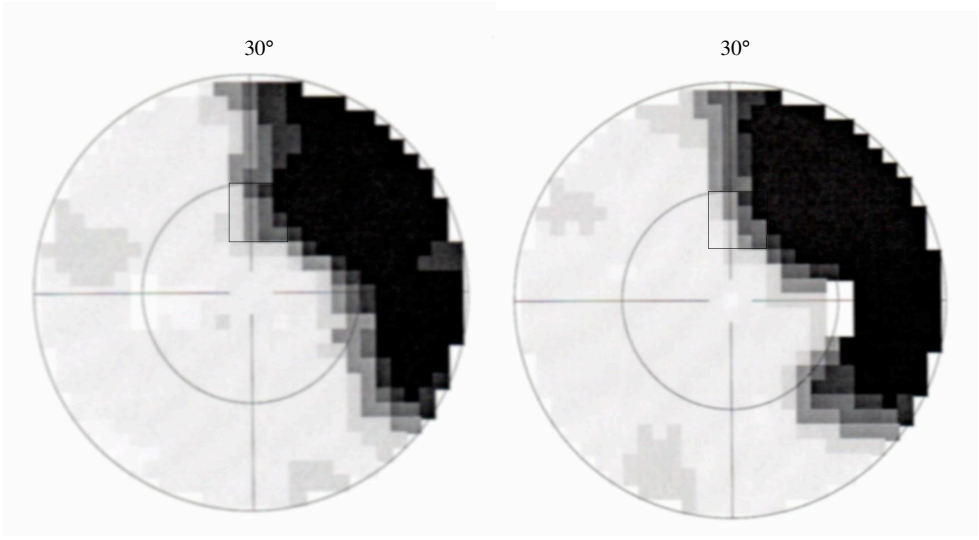
### Alterations in visual field morphology

As there was no possibility to record results for both eyes together, further analysis were done for each eye separately, starting with OS. Based on the results of the baseline condition it was decided for each patient individually where to present the stimulus, thus for each patient the stimulated area was an individually circumscribed region within the transition zone. As one rectangle in the static visual field perimetry represent $2°^2$ of visual angle, the degrees² of visual angle were summed up separately for the intact, for the relative blind and for the absolute blind fields.

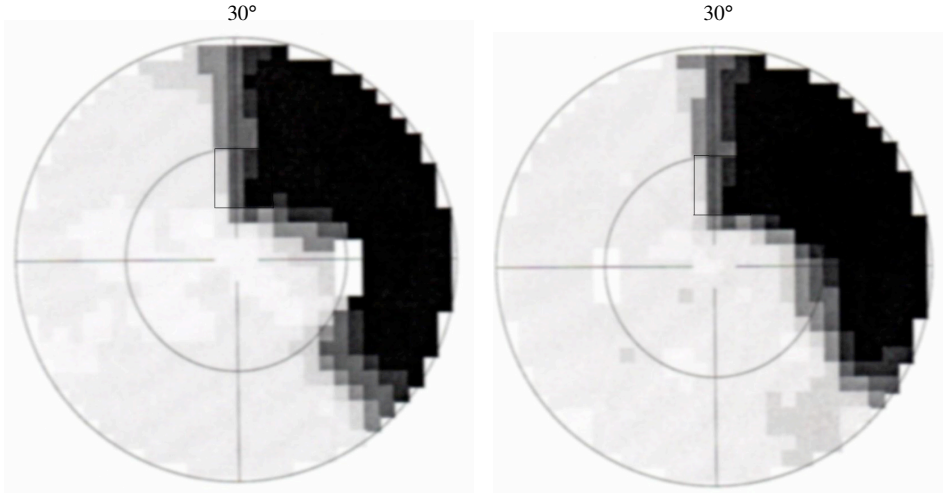
In a second step, the same procedure was conducted for the intact, the relative blind and absolute blind fields of the individually part of the transition zone of each post-treatment measures, which was conducted after each stimulation. These calculated degrees² of visual angle of the individually area of the transition zone were than compared to those calculated for the individually area of the transition zone of the baseline condition.

### Patient RP, Results of Experiment 5 (a)

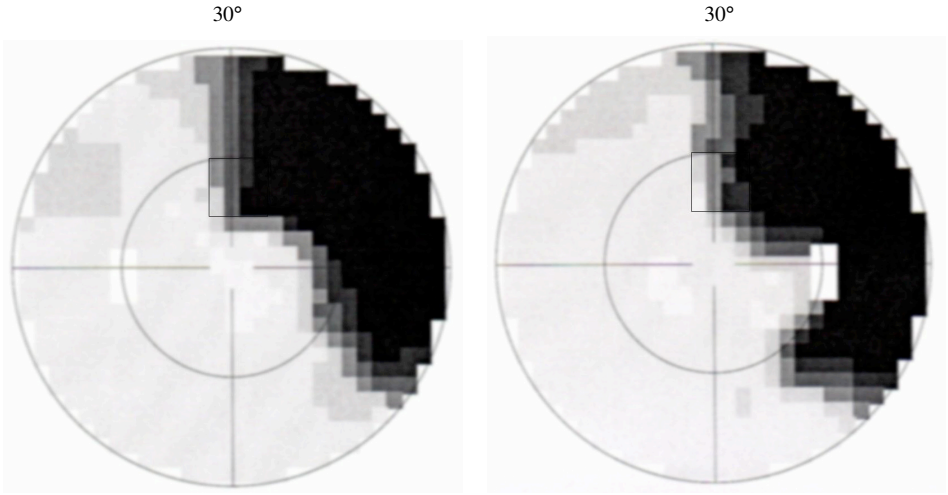
Nineteen days after determination of the baseline condition patient RP was examined. For the result of basic condition and post-treatment perimetry measures, with the marked stimulated area for Experiment 5 (a) in an overview see next page (Figure 5.II).



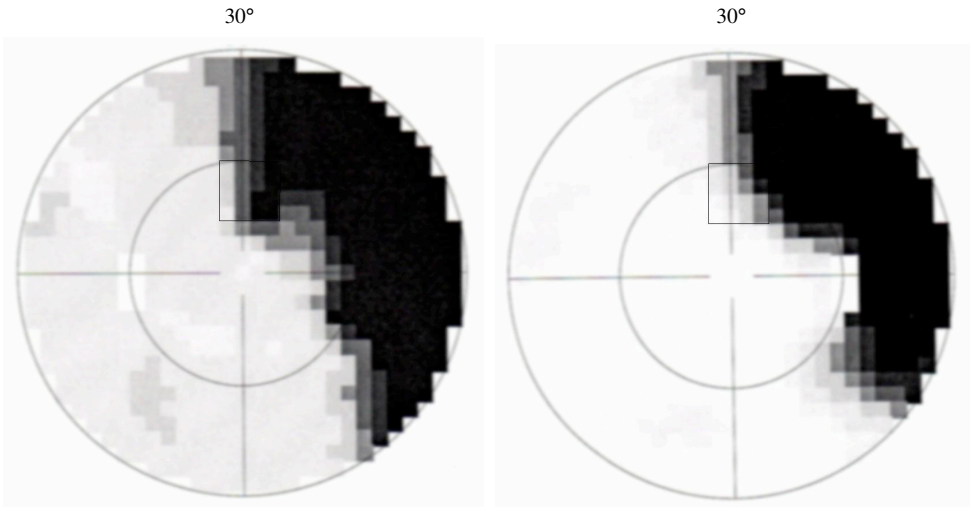

(a): (OS) baseline condition (b): (OD)



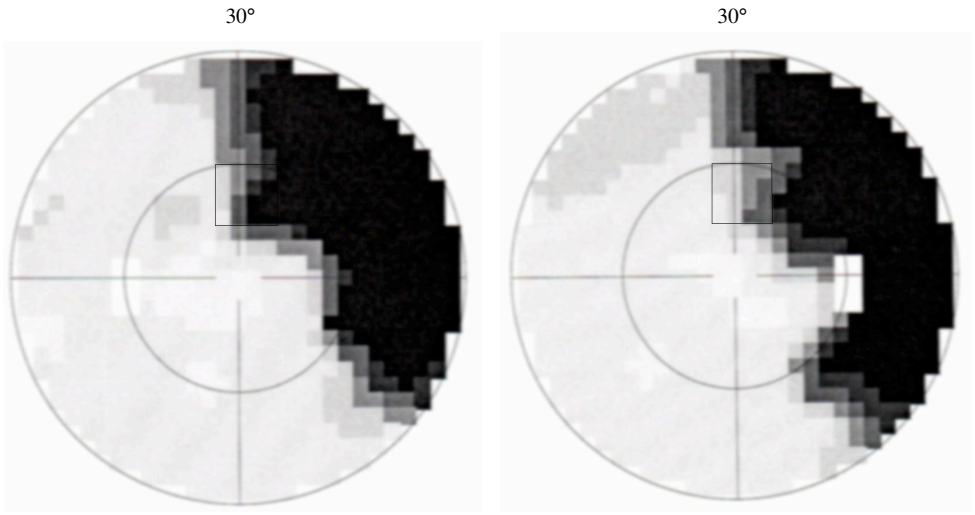

(c): OS 20 Hz (d): OD




(e): OS 27 Hz (f): OD




(g): OS 38 Hz (h): OD




(i): OS semi-static (j): OD

Figure 5.II (a) and (b): Patient RP (OS and OD): The results of the baseline condition. Each rectangle represents 2°² of visual angle. The white rectangles signify the intact fields (i.e. fully functional) visual field(s), the grey signify the relative blind and the black rectangles signify the absolute blind field(s.). The white vertical rectangle symbolised the blind spot. The temporal stimulated area of 8° x 8°²of visual angle signifies the black rectangle. Results of intact and defect fields after
(c-d) the 20-Hz stimulation, (e-f) the 27-Hz stimulation, (g-h) the 38-Hz stimulation and (i-j) the semi-static stimulation.

As illustrated in Figure 5.2 results revealed for OS no changes in the size of the intact field. Related to relative blind field, there is a decrease following all stimuli: 20 Hz (- 8°² of visual angle), 27 Hz (- 4°² of visual angle), 38 Hz (- 4°² of visual angle) and semi-static (- 2°² of visual angle). Accompanying this, the absolute blind fields increased following all frequency (20 Hz [+ 8°² of visual angle], 27 Hz [+ 4°² of visual angle], 38 Hz [+ 4°² of visual angle]) and semi-static (+ 2°² of visual angle) stimulations. For all values see in Table 5.2.

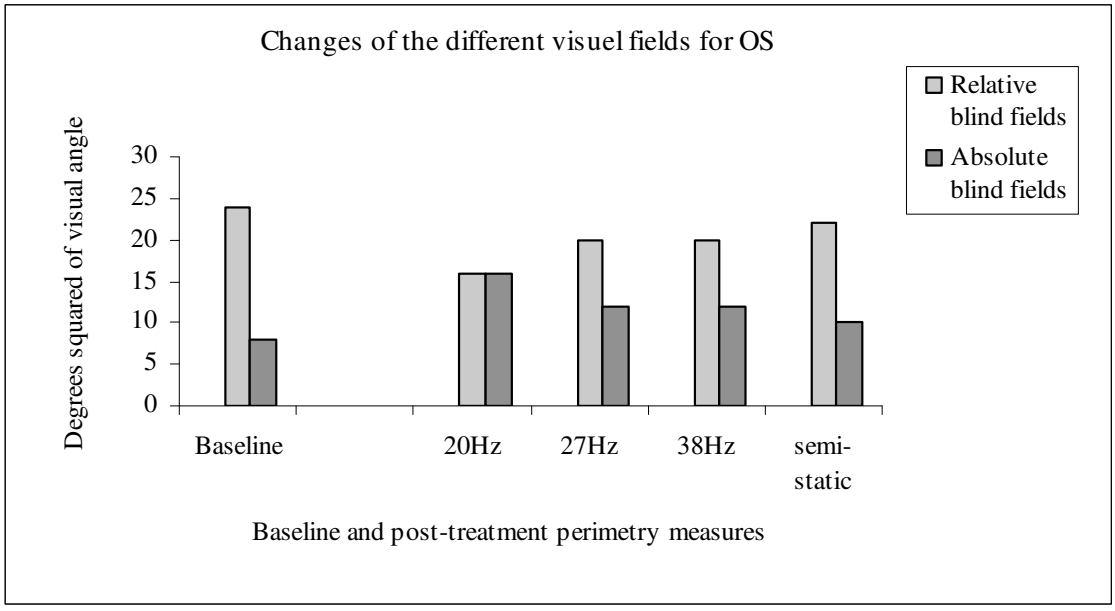



Figure 5.2: Patient RP (OS): Bars denote degrees² of visual angle for intact and defect fields in the transition zone. Relative blind field decreased in the size following all stimulations. Accompanying this, the absolute blind fields increased following all stimulations.

Table 5.2: Patient RP (OS and OD): Results of baseline condition and post-treatment measures.

| | OS | | | | | OD | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Degrees² of visual angle | | | | | Degrees² of visual angle | | | | |
| Fields of transition zone | Baseline | 20 Hz | 27 Hz | 38 Hz | semi-static | Baseline | 20 Hz | 27 Hz | 38 Hz | semi-static |
| Intact | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 8 | 0 |
| Relative blind | 24 | 16 | 20 | 20 | 22 | 24 | 20 | 26 | 22 | 32 |
| Absolute blind | 8 | 16 | 12 | 12 | 10 | 4 | 12 | 6 | 2 | 0 |

As illustrated in Figure 5.3 the results for OD were a decrease in the size of the intact fields following stimulation at 20 Hz (- 4°² of visual angle), 27 Hz (- 4°² of visual angle) and semi-static (- 4°² of visual angle) and an increase following stimulation at 38 Hz (+ 4°² of visual angle). Results for the relative blind field revealed a decrease following 20-Hz (- 4°² of visual angle) and 38-Hz (- 2°² of visual angle) stimulation and an increase following 27-Hz (+ 2°² of visual angle) and semi-static (+ 8°² of visual angle) stimulation. Results for the absolute blind fields revealed an increase at 20-Hz stimulation (+ 8°² of visual angle) and 27 Hz (+ 2°² of visual angle) and a decrease following stimulations at 38 Hz (- 2°² of visual angle) and semi-static (- 4°² of visual angle). For all values see Table 5.2.

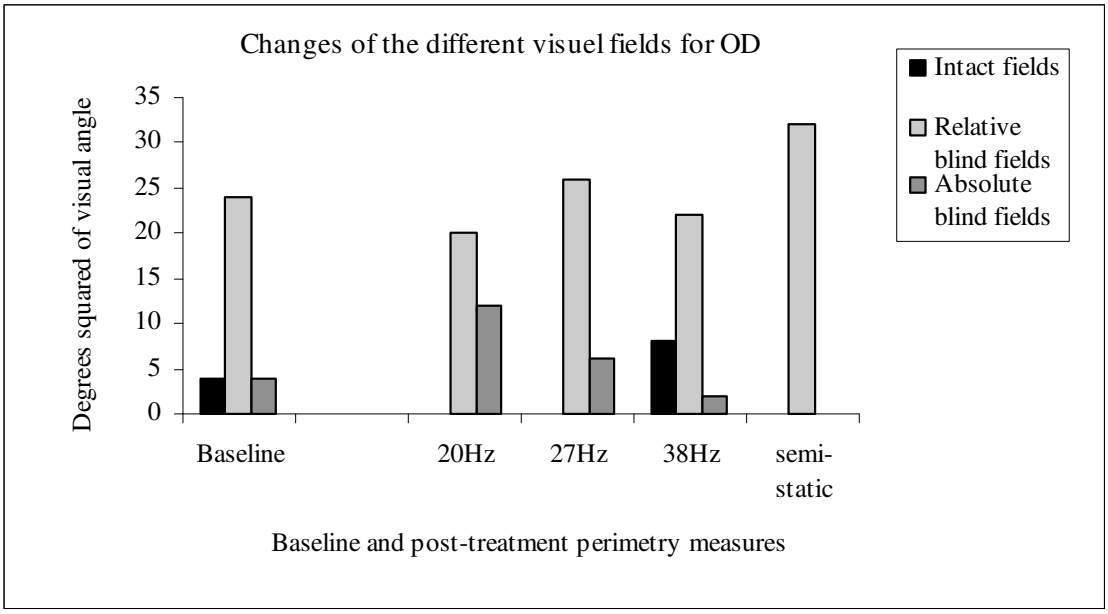



Figure 5.3: Patient RP (OD): Bars denote degrees² of visual angle for intact and defect fields in the transition zone. Intact fields decreased in the size following stimulations at 20 Hz, 27 Hz and semi-static and an increase following 38-Hz stimulation. Relative blind field decreased following stimulations at 20 Hz and 38 Hz and increased following 27-Hz and semi-static stimulation. Absolute blind field increased following 20-Hz and 27-Hz and decreased following 38-Hz and semi-static stimulation.

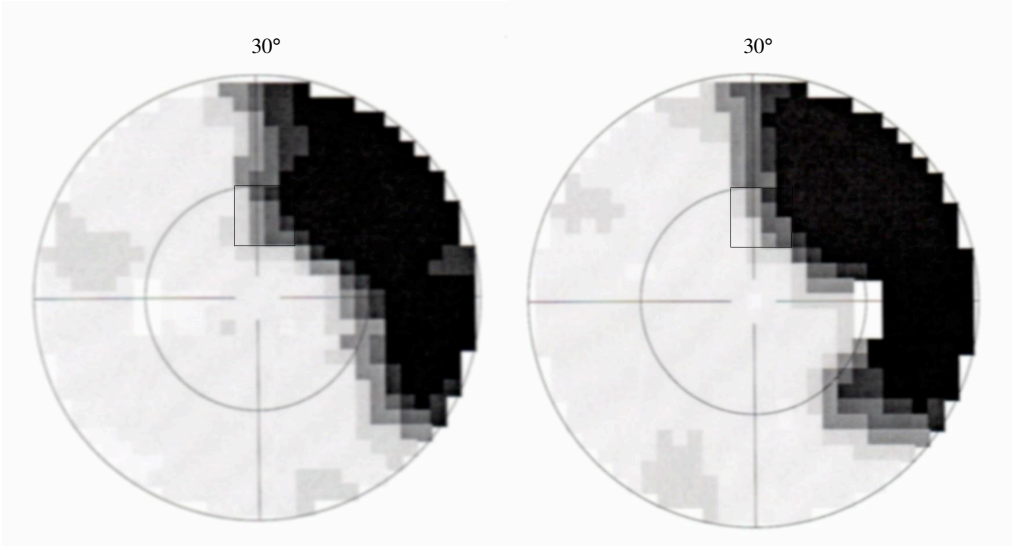
The calculated degrees² of visual angle for the intact and defect fields of the post-treatment measures were compared with the corresponding data given semi-static stimulation, as the semi-static stimulation is the experimental control condition. Results revealed for OS and OD no changes in the size of the intact fields, with one exception of OD for which results revealed an increase following 38-Hz stimulation (+ 8°² of visual angle). Related to relative blind field, there is a decrease of the size in OS and OD following all frequency stimulations (OS: 20 Hz [- 6°² of visual angle], 27 Hz [- 2°² of visual angle], 38 Hz [- 2°² of visual angles of visual angle] and OD: 20 Hz [- 12°² of visual angle], 27 Hz [- 6°² of visual angle], 38 Hz [- 10°² of visual angle]). Accompanying this, for OS and OD the absolute blind fields increased following all frequency stimulations (OS: 20 Hz [+ 6°² of visual angle], 27 Hz [+ 2°² of visual angle],

38 Hz [+ 2°² of visual angle] and OD: 20 Hz [+ 12°² of visual angle], 27 Hz [+ 6°² of visual angle], 38 Hz [+ 2°² of visual angle]). For all values see Table 5.2.

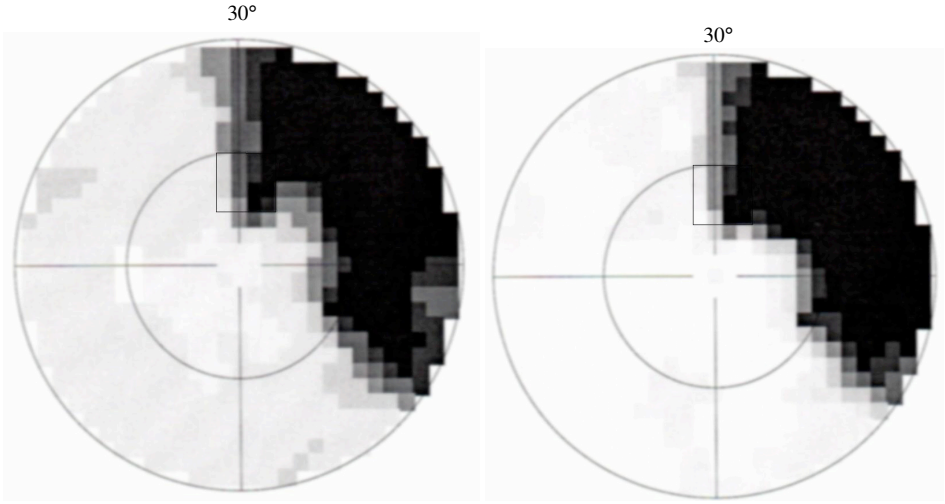
In summary in comparison to baseline condition and semi-static stimulation no changes in the size of the intact fields for OS, but an increase in OD following 38-Hz stimulation, due to both a shifting of relative and absolute blind fields. Furthermore for OS and OD changes in relative blind fields are associated with changes in the absolute blind fields; the increases and decreases changed with temporal and semi-static stimulation. In fact stimulation appeared to increase the area over which RP experienced absolute blindness: the increases and decreases changed with temporal and semi-static stimulation.

Patient RP, Results of Experiment 5 (b)

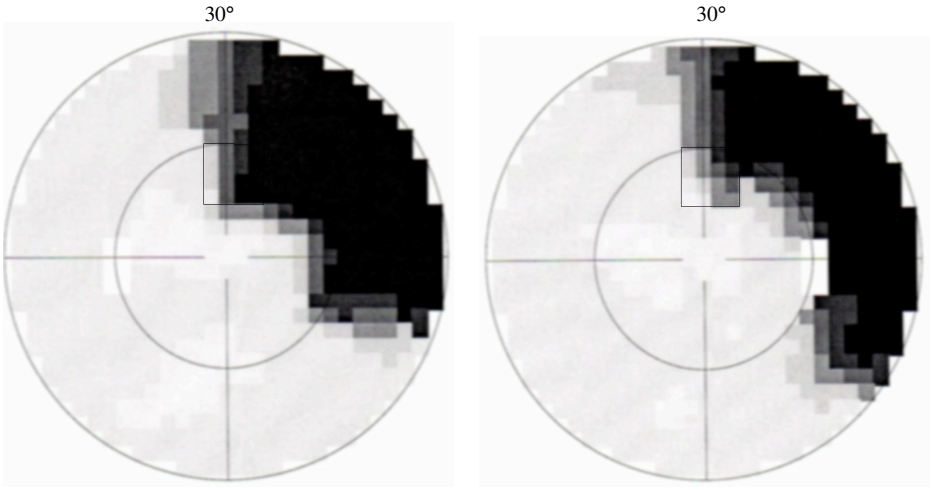
Thirty five days after determination of the baseline condition and sixteen days after Experiment 5 (a) patient RP was examined in further experiment (Experiment 5 [b]). Due to the results patient RP revealed in previously experiments (see Chapter III) and in Experiment 5 (a), she was examined again with the same procedure, but with the following exceptions: Experiment 5 (b) differed from Experiment 5 (a), in that stimulus presentation was enveloped within a cosine function as described for Experiment 2 (see Chapter III). For the result of basic condition and post-treatment perimetry measures, with the marked stimulated area for Experiment 5 (b) in an overview see next page (Figure 5.III).




(a): OS baseline condition (b): OD




(c): OS 20 Hz (d): OD




(e): OS 27 Hz (f): OD

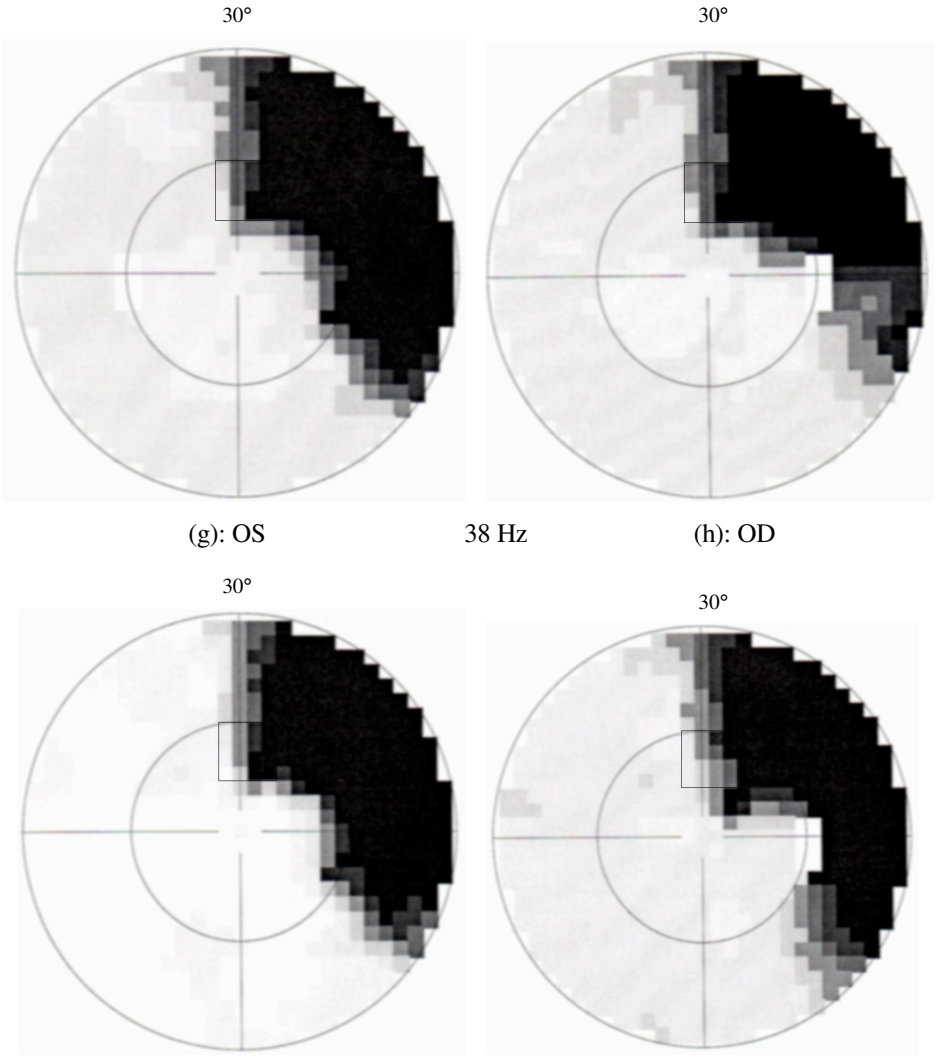



Figure 5.III (a) and (b): Patient RP (OS and OD): The results of the baseline condition. Each rectangle represents 2°² of visual angle. The white rectangles signify the intact fields (i.e. fully functional) visual field(s), the grey signify the relative blind and the black rectangles signify the absolute blind field(s.). The white vertical rectangle symbolised the blind spot. The temporal stimulated area of 8° x 8°²of visual angle signifies the black rectangle. Results of intact and defect fields after
(c-d) the 20-Hz stimulation, (e-f) the 27-Hz stimulation, (g-h) the 38-Hz stimulation and (i-j) the semi-static stimulation.

As illustrated in Figure 5.4 results revealed for OS no changes in the size of the intact fields, with one exception of an increase following the 27-Hz stimulation (+ 2°² of visual angle). Related to relative blind fields, there is a decrease following all frequency stimulations: 20 Hz (- 2°² of visual angle), 27 Hz (- 6°² of visual angle) and for the 38 Hz (- 4°² of visual angle), with one exception of an increase following the semi-static stimulation (+ 2°² of visual angle). Accompanying this, the absolute blind fields, increased for all frequency stimulations (20 Hz [+ 2°² of visual angle], 27 Hz [+ 4°² of visual angle] and 38 Hz [+ 4°² of visual angle]), with one exception of a decrease following the semi-static stimulation (- 2°² of visual angle). For all values see Table 5.3.

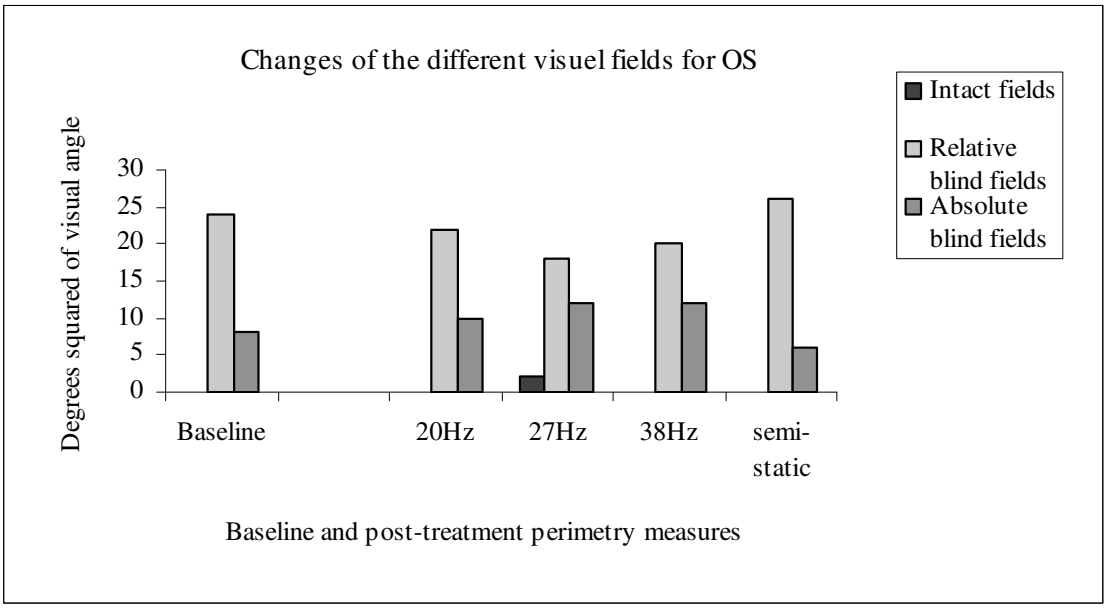



Figure 5.4: Patient RP (OS): Bars denote degrees² of visual angle for intact and defect fields in the transition zone. Results revealed an increase in the intact fields following frequency stimulation at 27 Hz. Relative blind fields decreased following stimulations at 20 Hz, 27 Hz and 38 Hz and an increase following semi-static stimulation. Absolute blind field increased following all frequency stimulations (20 Hz and 27 Hz, with peak at 38 Hz) and decreased following semi-static stimulation.

Table 5.3: Patient RP (OS and OD): Results of baseline condition and post-treatment measures.

| | OS | | | | | OD | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Degrees² of visual angle | | | | | Degrees² of visual angle | | | | |
| Fields of transition zone | Baseline | 20 Hz | 27 Hz | 38 Hz | semi-static | Baseline | 20 Hz | 27 Hz | 38 Hz | semi-static |
| Intact | 0 | 0 | 2 | 0 | 0 | 4 | 0 | 2 | 2 | 8 |
| Relative blind | 24 | 22 | 18 | 20 | 26 | 24 | 20 | 28 | 18 | 12 |
| Absolute blind | 8 | 10 | 12 | 12 | 6 | 4 | 12 | 2 | 12 | 12 |

As illustrated in Figure 5.5 results revealed for OD a decrease in the size of the intact fields following all frequency stimulations (20 Hz [- 4°² of visual angle], 27 Hz [- 2°² of visual angle] and 38 Hz [- 2°² of visual angle]), with one exception of an increase following semi-static stimulation (+ 4°² of visual angle). Results for the relative blind fields revealed a decrease following stimulations at semi-static (- 12°² of visual angle), 20 Hz (- 4°² of visual angle) and 38 Hz (- 6°² of visual angle), with one exception of an increase following 27-Hz stimulation (+ 4°² of visual angle). Results for the absolute blind fields revealed an increase in the size following stimulations at 20 Hz, 38 Hz and semi-static (for all + 8°² of visual angle), with one exception of a decrease in the size following 27-Hz stimulation (- 2°² of visual angle). For all values see Table 5.3.

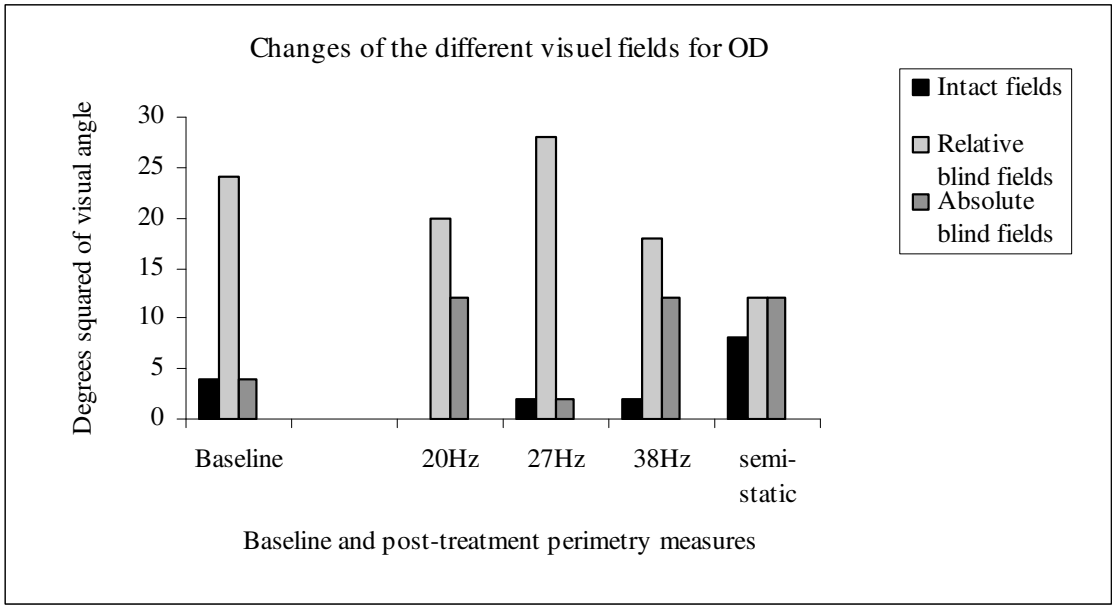



Figure 5.5: Patient RP (OD): Bars denote degrees² of visual angle for intact and defect fields in the transition zone. Results revealed a decrease in the size of the intact fields following all frequency stimulations: 20 Hz, 27 Hz and 38 Hz and an increase following semi-static stimulation. Relative blind fields decreased in the size following stimulations at 20 Hz, 38 Hz and semi-static and an increase following 27 Hz. Absolute blind fields increased in the sized following stimulations at 20 Hz, 38 Hz and semi-static and a decrease following 27-Hz stimulation.

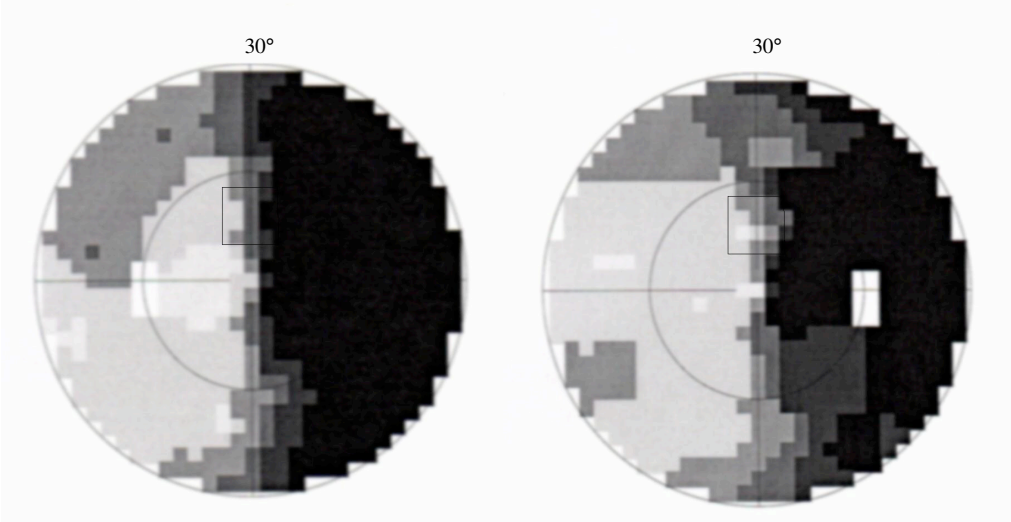
The calculated degrees² of visual angle for the intact and defect fields of the post-treatment measures were compared with the corresponding data given semi-static stimulation, as the semi-static stimulation is the experimental control condition. Results revealed for OS no changes in the size of the intact fields, with one exception of an increase following 27-Hz (+ 2°² of visual angle) stimulation. Related to the relative blind fields, there is a decrease following all frequency stimulations: 20 Hz (- 4°² of visual angle), 27 Hz (- 8°² of visual angle) and 38 Hz (- 6°² of visual angle). Accompanying this, the absolute blind fields increased for all frequency stimulations (20 Hz [+ 4°² of visual angle], 27 Hz [+ 6°² of visual angle] and 38 Hz [+ 6°² of visual angle]). Results revealed for OD a decrease of the intact fields following all frequency stimulations: (20 Hz [- 8°² of visual angle], 27 Hz [- 6°² of visual angle] and 38 Hz [- 6°² of visual angle]). Relative

blind fields increased following all frequency stimulations: 20 Hz (+ 8°² of visual angle), 27 Hz (+ 16°² of visual angle) and 38 Hz (+ 6°² of visual angle). Related to absolute blind fields, there is a decrease following 27 Hz stimulation (- 10°² of visual angle) and no changes following 20 Hz and 38 Hz. For all values see Table 5.3.

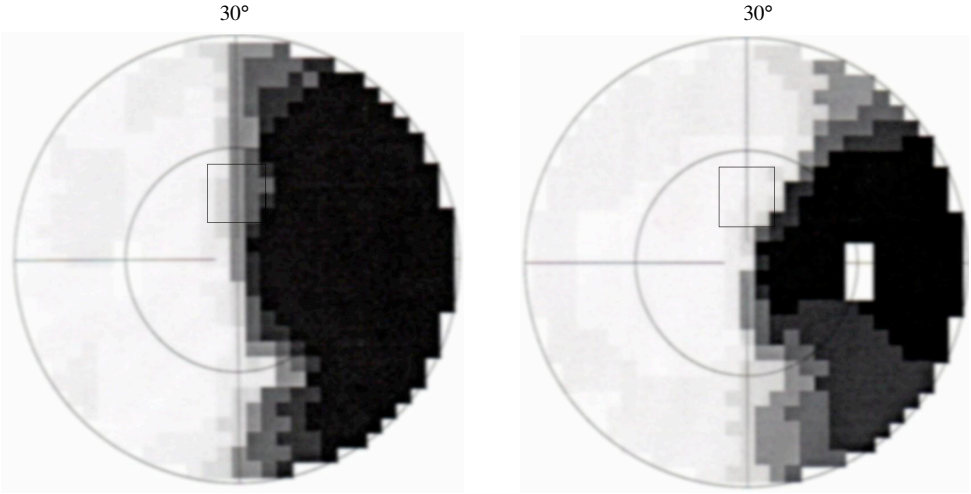
In summary in comparison to baseline condition for OS an increase in the size of intact fields following 27 Hz and for OD an increase following 27, 38 Hz and with peak following semi-static stimulation. Furthermore for OS and OD the relative blind field was reduced, with two exceptions of OS of an increase at semi-static stimulation and for OD at 27 Hz. Accompanying this, the absolute blind fields increased for OS and OD following all stimuli, with one exception for OS of a decrease at semi-static stimulation and for OD of a decrease at 27 Hz. In comparison to semi-static stimulation, there was an increase for OS in the size of the intact fields to observe following 27-Hz stimulation and a decrease for OD following all frequency stimulations. The relative blind fields for OS decreased for all frequency stimulations, while for OD relative blind fields increased. Accompanying this, the absolute blind fields for OS increased for all frequency stimulations, while for OD absolute blind fields decreased following 27-Hz stimulation.

Patient FS, Results of Experiment 5 (a)

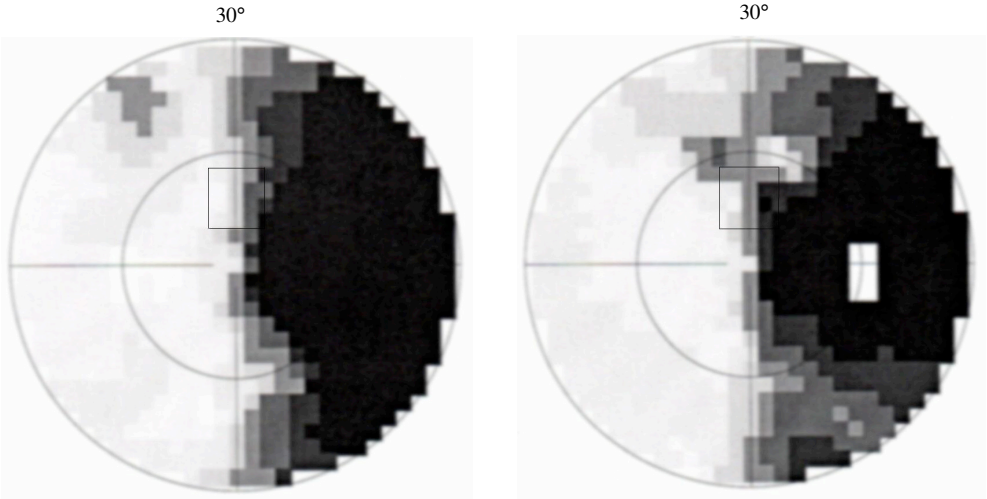
Seventeen days after determination of the baseline condition patient FS was examined. For the result of basic condition and post-treatment perimetry measures, with the marked stimulated area for Experiment 5 (a) in an overview see next page (Figure 5.IV).




(a): (OS) baseline condition (b): (OD)




(c): OS 20 Hz (d): OD




(e): OS 27 Hz (f): OD

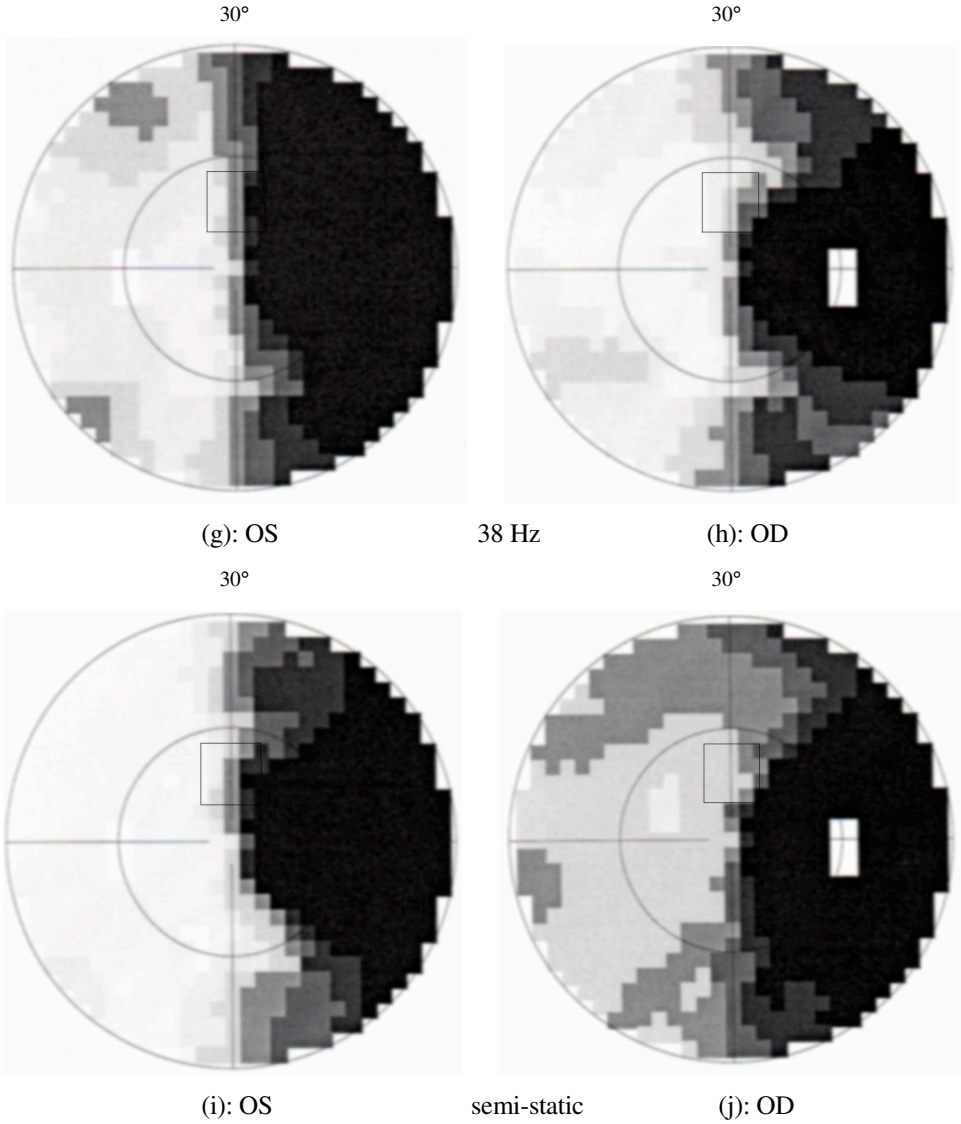



Figure 5.IV (a) and (b): Patient FS (OS and OD): The results of the baseline condition. Each rectangle represents 2°² of visual angle. The white rectangles signify the intact fields (i.e. fully functional) visual field(s), the grey signify the relative blind and the black rectangles signify the absolute blind field(s.). The white vertical rectangle symbolised the blind spot. The temporal stimulated area of 8° x 8°²of visual angle signifies the black rectangle. Results of intact and defect fields after
(c-d) the 20-Hz stimulation, (e-f) the 27-Hz stimulation, (g-h) the 38-Hz stimulation and (i-j) the semi-static stimulation.

As illustrated in Figure 5.6 results revealed for OS an increase in the size of the intact fields following all stimuli: (20 Hz [+ 3°² of visual angle], 27 Hz and 38 Hz [both + 8°² of visual angle] and semi-static [+ 10°² of visual angle]). Related to the relative blind fields, there is a decrease following stimulation at 27 Hz (-1°² of visual angle), 38 Hz (-8°² of visual angle) and semi-static (- 6°² of visual angle) and an increase following stimulation at 20 Hz (+ 4°² of visual angle). Related to absolute blind fields there is a decrease following 20 Hz, 27 Hz (both - 7°² of visual angle), semi-static (- 4°² of visual angle) and were equal of the size following stimulation at 38 Hz. For all values see Table 5.4.

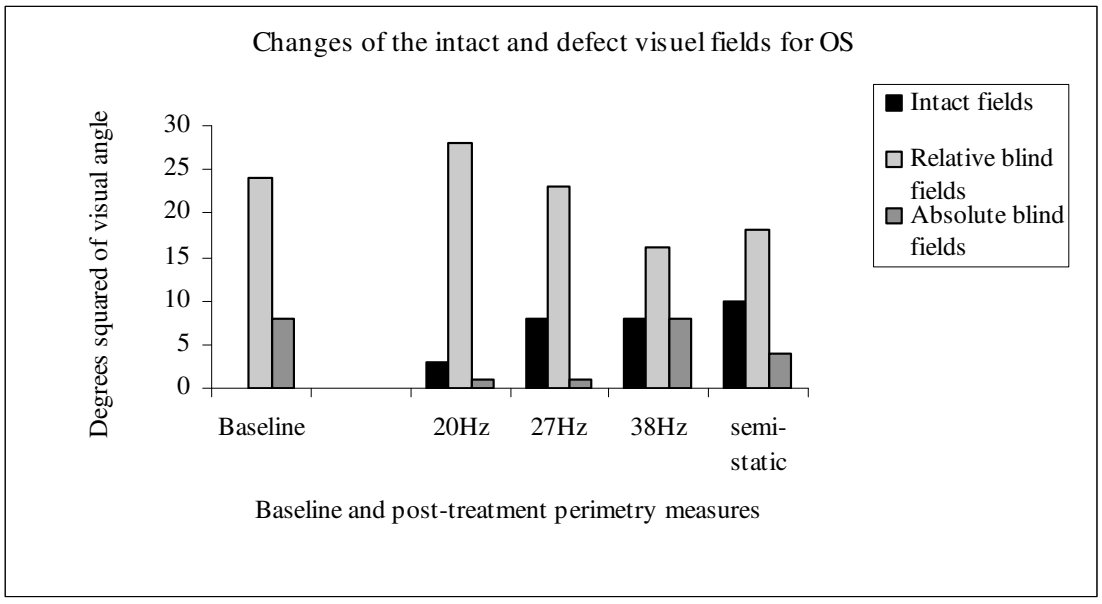



Figure 5.6: Patient FS (OS): Bars denote degrees² of visual angle for intact and defect fields in the transition zone. Results revealed an increase of the size in the intact fields following all stimulations. Related to relative blind field, there is a decrease following stimulations at 27 Hz, 38 Hz and semi-static and an increase at 20-Hz stimulation. Related to absolute blind field, there is a decrease following 20-Hz, 27-Hz and semi-static stimulation and were equal of size following 38-Hz stimulation.

Table 5.4: Patient FS (OS and OD): Results of baseline condition and post-treatment measures.

| | OS | | | | | OD | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Degrees² of visual angle | | | | | Degrees² of visual angle | | | | |
| Fields of transition zone | Baseline | 20 Hz | 27 Hz | 38 Hz | semi-static | Baseline | 20 Hz | 27 Hz | 38 Hz | semi-static |
| Intact | 0 | 3 | 8 | 8 | 10 | 2 | 21 | 3 | 12 | 0 |
| Relative blind | 24 | 28 | 23 | 16 | 18 | 28 | 10 | 26 | 19 | 31 |
| Absolute blind | 8 | 1 | 1 | 8 | 4 | 2 | 1 | 3 | 1 | 1 |

As illustrated in Figure 5.7 results revealed for OD a very substantial increase in the size of the intact fields following all frequency presentations (particularly at 20 Hz [+ 19°² of visual angle], but also at 27 Hz [+ 1°² of visual angle] and 38 Hz [+ 10°² of visual angle]) and a decrease following semi-static stimulation (- 2°² of visual angle). Related to the relative blind fields, there is a decrease following all stimulations (20 Hz [- 19°² of visual angle], 38 Hz [- 9°² of visual angle] and 27 [- 2°² of visual angle]), with one exception of an increase following semi-static (+ 3°² of visual angle) stimulation. Related to the absolute blind fields, results revealed a decrease following stimuli at 20 Hz (- 1°² of visual angle), 38 Hz (- 1°² of visual angle) and semi-static (- 1°² of visual angle) and an increase following stimulation at 27 Hz (+ 1°² of visual angle). For all values see Table 5.4.

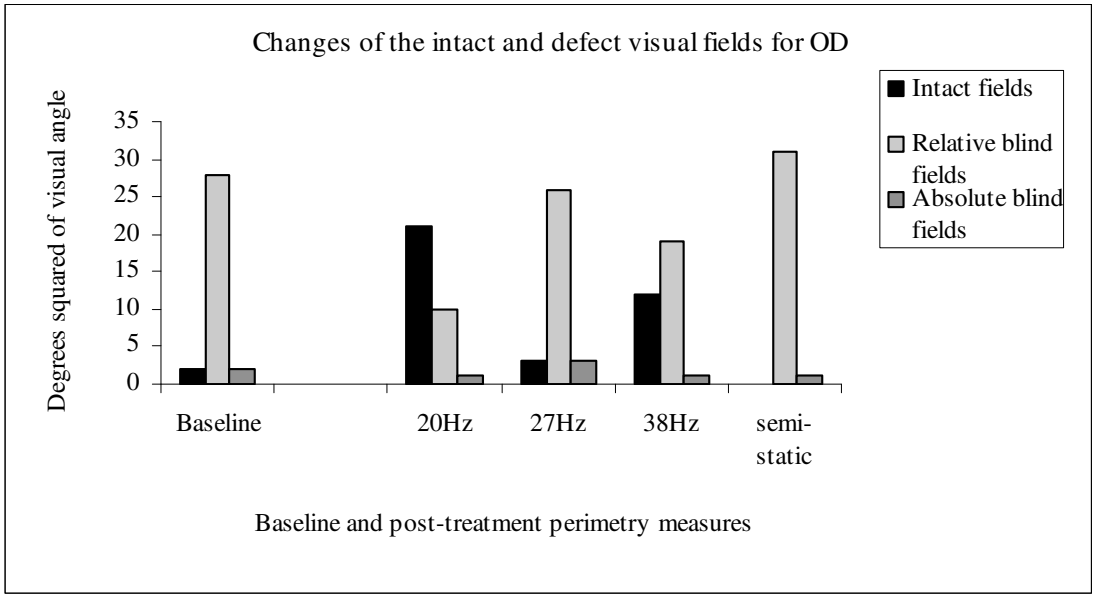



Figure 5.7: Patient FS (OD): Bars denote degrees² of visual angle for intact and defect fields in the transition zone. Results revealed an increase in the size of the intact fields following all frequency stimulations, with peak at 20 Hz and a decrease following semi-static stimulation. Relative blind field decreased in the size following stimulations 20 Hz, 27 Hz and 38 Hz and an increase following semi-static stimulation. Absolute blind fields decrease for stimulations 20 Hz, 38 Hz and semi-static and an increase following 27 Hz.

Furthermore the calculated degrees² of visual angle for the intact and defect fields of the post-treatment measures were compared with the corresponding data given semi-static stimulation, as the semi-static stimulation is the experimental control condition. Results revealed for OS a decrease in the size of the intact field following all frequency stimulations: 20 Hz (- 7°² of visual angle), 27 Hz (- 2°² of visual angle) and 38 Hz (- 2°² of visual angle). Related to the relative blind fields, there is an increase following stimulations at 20 Hz (+ 10°² of visual angle), 27 Hz (+ 5°² of visual angle) and a decrease following stimulation at 38 Hz (- 2°² of visual angle). Related to the absolute blind fields, there is a decrease following stimulations at 20 Hz (- 3°² of visual angle) and 27 Hz (- 3°² of visual angle) and an increase following stimulation at 38 Hz (+ 4°² of visual angle).

Results revealed for OD an increase of the intact fields following all frequency stimuli: 20 Hz (+ 21°² of visual angle), 27 Hz (+ 3°² of visual angle) and 38 Hz (+ 12°² of visual angle). Accompanying this, the related to relative blind fields decreased following all frequency stimulations (20 Hz [- 21°² of visual angle], 27 Hz [- 5°² of visual angle] and 38 Hz [- 12°² of visual angle]). Related to absolute blind fields, results revealed no changes, with one exception of an increase in the size following 27-Hz stimulation (+ 2° of visual angle). For all values see Table 5.4.

In summary in comparison to baseline condition the results for OS showed that the size of the intact fields increased following stimulation at all frequencies, although the largest increase followed semi-static stimulation. The largest decrease in size was for the relative blind fields following 38 Hz and semi-static stimulation and the largest decrease in the absolute blind fields was found following 20-Hz and 27-Hz stimulation. In comparison to the baseline condition for OD the size of the intact fields increased given all frequency stimulations with the largest gain following 20-Hz presentation. There was a reduction in the size in the intact fields following semi-static stimulation, while decreases in the size of the relative blind fields were found following 20, 27 and 38 Hz. The largest decrease was found for the absolute blind fields given 20 Hz, 38 Hz and semi-static presentations. In comparison to the semi-static stimulation and for OS results revealed a decrease in the size of intact fields following all frequency stimulations and for OD an increase following all frequency stimulations. For OS relative blind fields increased following all frequency stimulations and for OD decreased following all frequency stimulations. For OS absolute blind fields decreased following all frequency stimulations,

with one exception of an increase given 38-Hz stimulation. For OD absolute blind fields did not change following all frequency stimulations, except of an increase given 27 Hz.

Patient FS, Results of Experiment 5 (b)

Ten days after Experiment 5 (a) patient FS was examined in further experiment (Experiment 5 [b]), by stimulating his transition zone given 27 Hz. This was done for examining a control condition in relation to his good results given 20 Hz in Experiment 5 (a). The method of Experiment 5 (b) was complete identical to Experiment 5 (a), with two exceptions: a) prior to Experiment 5 (b) an extra baseline condition was conducted; this was possible as we only conducted one temporal stimulation and its corresponding static visual field perimetry, thus considerable time and effort on the part of the patient was less than in Experiment 5 (a). Based on the results of the baseline condition, the location of presented stimuli changed in Experiment 5 (b) so that x (axis of abscissa) = + 1°² of visual angle and on y (axis of ordinates) = +5°² of visual angle. Experiment 5 (b) lasted for approximately three hours; there were no longer breaks. For the result of basic condition and post-treatment perimetry measures, with the marked stimulated area for Experiment 5 (b) in an overview see next page (Figure 5.V).

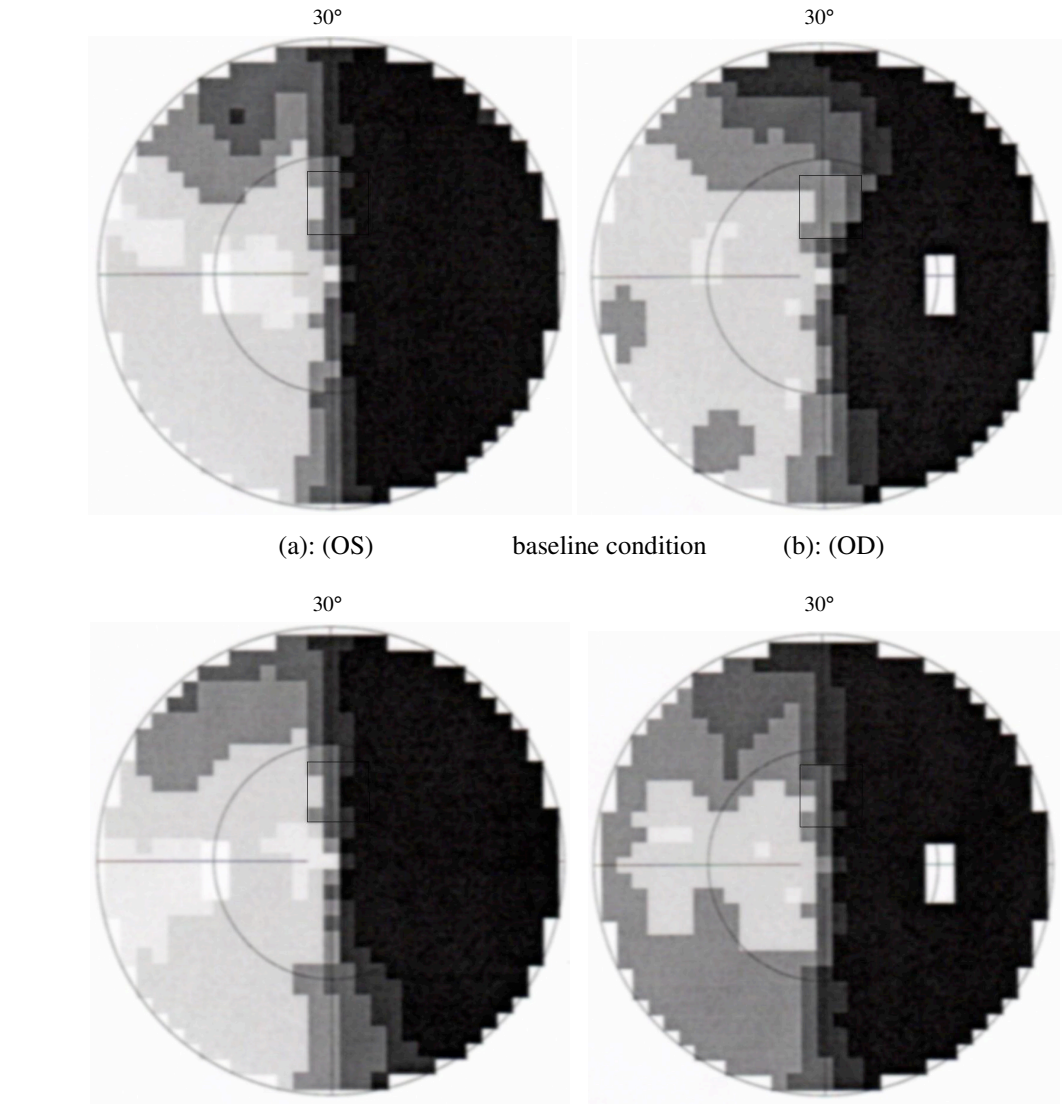



Figure 5.V (a) and (b): Patient FS (OS and OD): The results of the baseline condition. Each rectangle represents $2°^2$ of visual angle. The white rectangles signify the intact fields (i.e. fully functional) visual field(s), the grey signify the relative blind and the black rectangles signify the absolute blind field(s.). The white vertical rectangle symbolised the blind spot. The temporal stimulated area of 8° x $8°^2$of visual angle signifies the black rectangle.
(c-d) shows the results of intact and defect fields after the 27-Hz stimulation.

The results revealed for OS no changes in the size of the intact fields, relative and absolute blind fields. For all values see Table 5.5. As illustrated in Figure 5.8 results revealed for OD no changes in the size of the intact fields. Results for the relative blind field revealed a decrease following stimulation at 27 Hz (- 10°² of visual angle). Accompanying this, the absolute blind fields increased following stimulation at 27 Hz (+ 10°² of visual angle). For all values see Table 5.5.

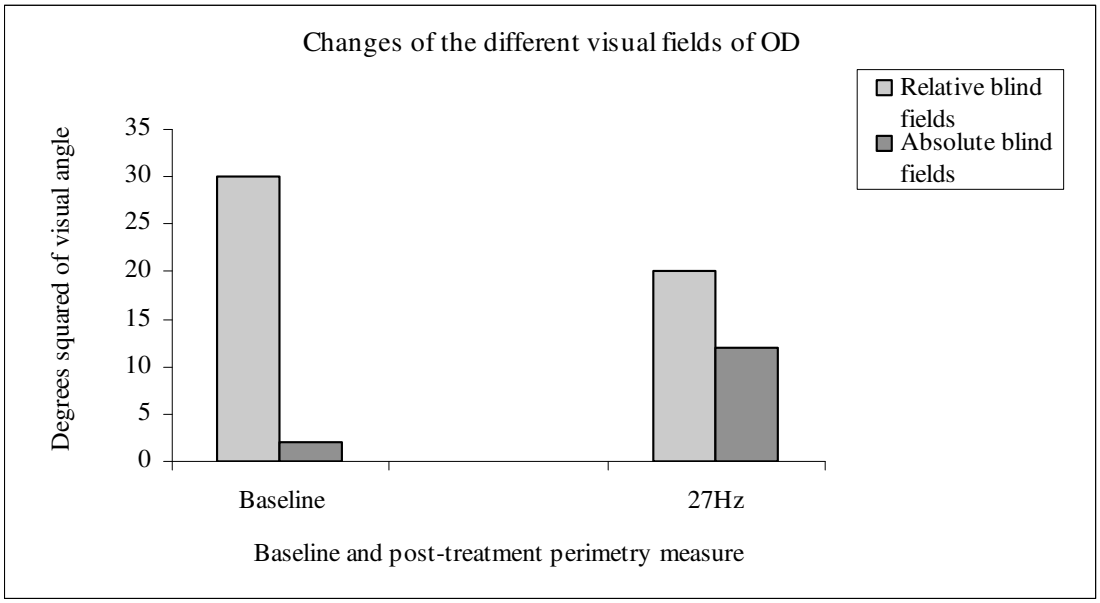



Figure 5.8: Patient FS (OD): Bars denote degrees² of visual angle for intact and defect fields in the transition zone. Results revealed no changes in the size of the intact fields. Relative blind fields decreased following 27-Hz stimulation. Accompanying this, the absolute blind fields increased following 27-Hz stimulation.

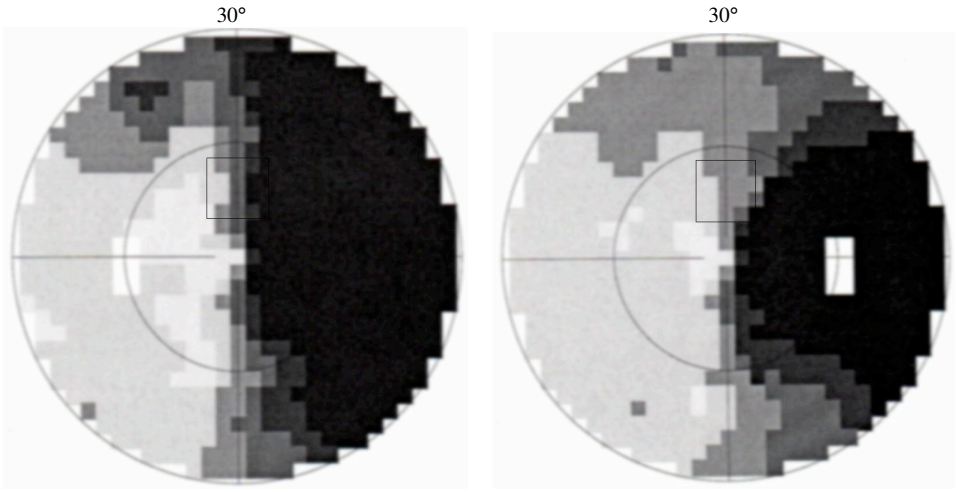
Table 5.5: Patient FS (OS and OD): Results of baseline condition and post-treatment measure.

| Fields of transition zone | OS Degrees² of visual angle | | OD Degrees² of visual angle | |
|---|---|---|---|---|
| | Baseline | 27 Hz | Baseline | 27 Hz |
| Intact | 0 | 0 | 0 | 0 |
| Relative blind | 20 | 20 | 30 | 20 |
| Absolute blind | 12 | 12 | 2 | 12 |

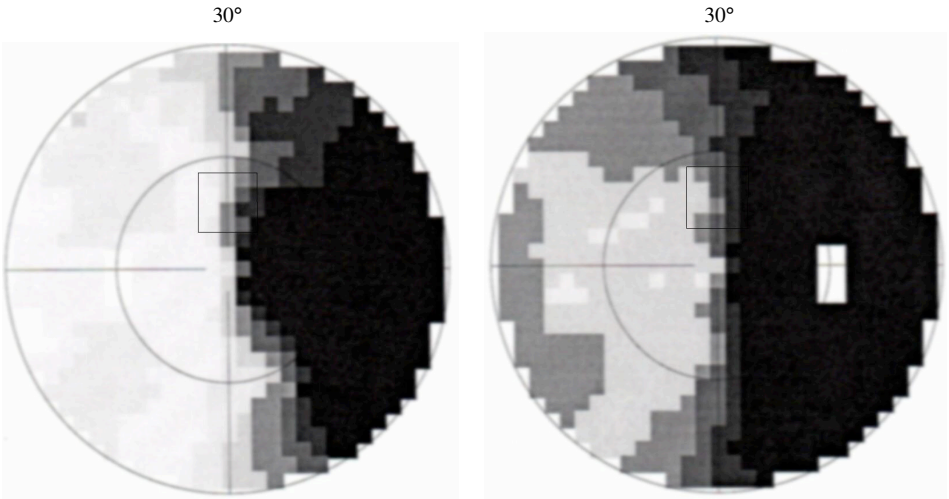
Patient FS, Results of Experiment 5 (c)

Two days after Experiment 5 (b) patient FS was examined in further experiment (Experiment 5 [c]), by stimulating his transition zone given 20 Hz. This was done for examining a repetition of the high increase of the size of the intact fields, patient FS showed in Experiment 5(a) following 20 Hz. The method of Experiment 5 (c) was complete identical to Experiment 5 (a), with two exceptions: a) prior to Experiment 5 (c) an extra baseline condition was conducted; this was possible as only one temporal stimulation and its corresponding static visual field perimetry was conducted, thus considerable time and effort on the part of the patient was less than in Experiment 5 (a). Furthermore a follow-up static visual field perimetry measure after a one-hour break was conducted to examine a possible long-term effect of the increased size of the intact fields following 20-Hz stimulation. Experiment 5 (c) lasted for approximately four hours; there were no longer breaks, except of the one-hour break prior to the follow-up measure.

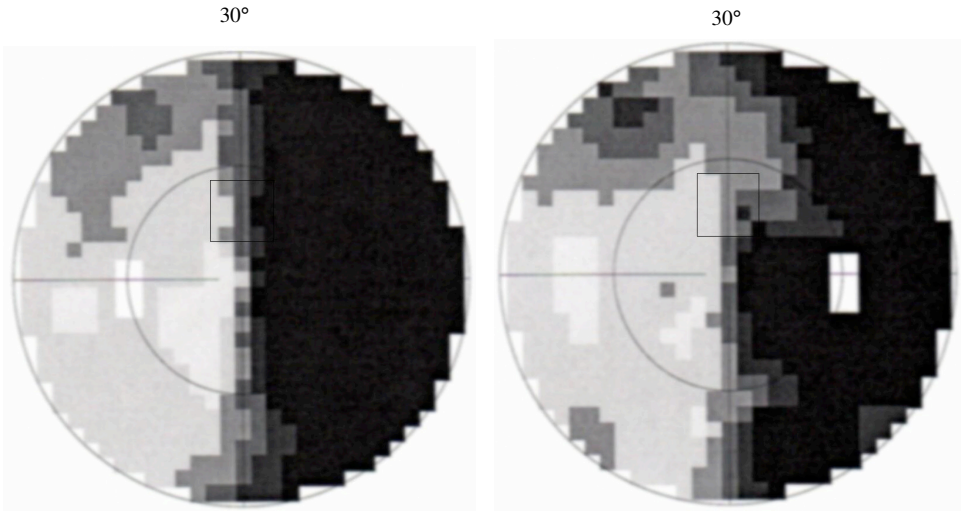
The result of basic condition and post-treatment perimetry measures, with the marked stimulated area for Experiment 5 (c) in an overview:




(a): (OS) baseline condition (b): (OD)




(c): OS 20 Hz (d): OD




(a): (OS) follow up (b): (OD)

Figure 5.VI (a) and (b): Patient FS (OS and OD): The results of the baseline condition. Each rectangle represents 2°² of visual angle. The white rectangles signify the intact fields (i.e. fully functional) visual field(s), the grey signify the relative blind and the black rectangles signify the absolute blind field(s.). The white vertical rectangle symbolised the blind spot. The temporal stimulated area of 8° x 8°²of visual angle signifies the black rectangle. Results of intact and defect fields after
(c-d) the 20-Hz stimulation and (e-f) one-hour break (follow-up measure).

As illustrated in Figure 5.9 the results revealed for OS an increase of the size in the intact fields following stimulation at 20 Hz (+ 7°² of visual angle). The follow-up measure one hour later revealed a decrease of intact fields (- 8°² of visual angle), thus the size of the intact fields were even more reduced than revealed for the baseline condition. Related to relative blind fields, there are no changes to observe following stimulation at 20 Hz and an increase following the follow-up measure (+ 1°² of visual angle). Related to absolute bind fields there is a decrease following stimulation at 20 Hz (- 7°² of visual angle) and no changes after the one-hour break. For all values see Table 5.6.

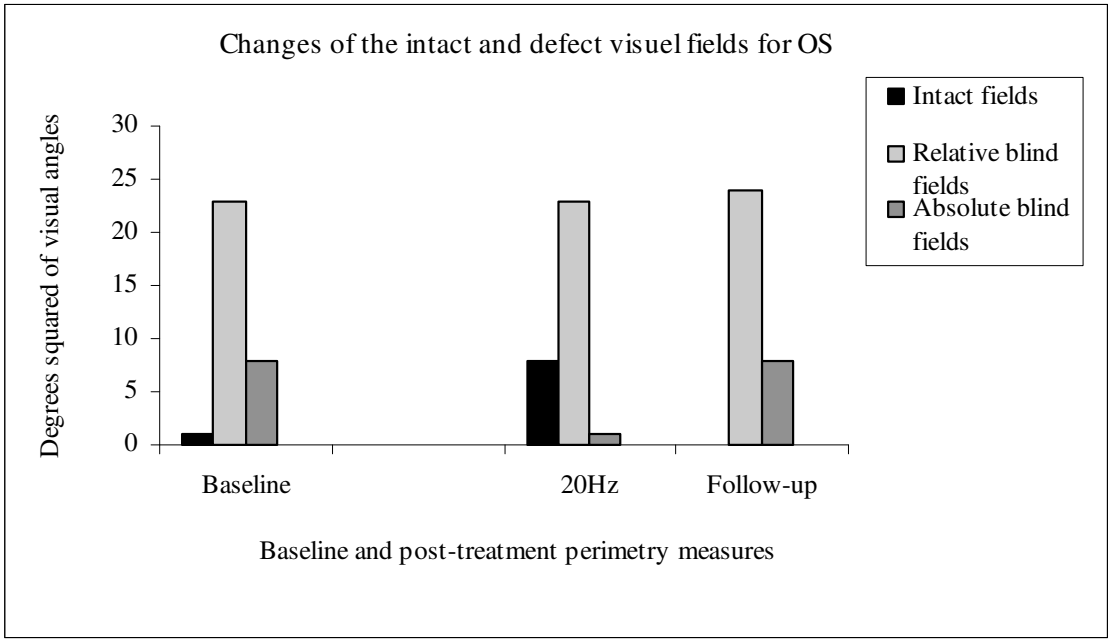



Figure 5.9: Patient FS (OS): Bars denote degrees² of visual angle for intact and defect fields in the transition zone. Results revealed for OS an increase of the size in the intact fields following 20 Hz stimulation and a decrease after the one-hour break (follow-up measure). Relative blind fields have not changed in the size following the 20-Hz stimulation and increased after the one-hour break (follow-up measure). Absolute bind fields decreased following 20-Hz stimulation and increased again after the one-hour break (follow-up measure).

Table 5.6: Patient FS (OS and OD): Results of baseline condition, post-treatment perimetry measures after 20 Hz stimulation and after the one-hour break (follow-up measure).

| Fields of transition zone | OS Degrees² of visual angle | | | OD Degrees² of visual angle | | |
|---|---|---|---|---|---|---|
| | Baseline | 20 Hz | follow-up | Baseline | 20 Hz | follow-up |
| Intact | 1 | 8 | 0 | 0 | 0 | 0 |
| Relative blind | 23 | 23 | 24 | 31 | 28 | 29 |
| Absolute blind | 8 | 1 | 8 | 1 | 4 | 3 |

As illustrated in Figure 5.10 results revealed for OD no changes of the size in the intact fields. Related to the relative blind fields, there is a decrease following stimulation at 20 Hz (- 3°² of visual angle) and the follow-up measure (- 2°² of visual angle), thus in the follow-up measure the relative blind fields increased again, almost revealing the same size than revealed for the baseline condition. Accompanying this, the absolute blind fields increased following stimulation at 20 Hz (+ 3°² of visual angle) and after the one-hour break (follow-up measure = + 2°² of visual angle), thus in the follow-up measure the absolute blind fields decreased again, almost revealing the same size than revealed for the baseline condition. For all values see Table 5.6.

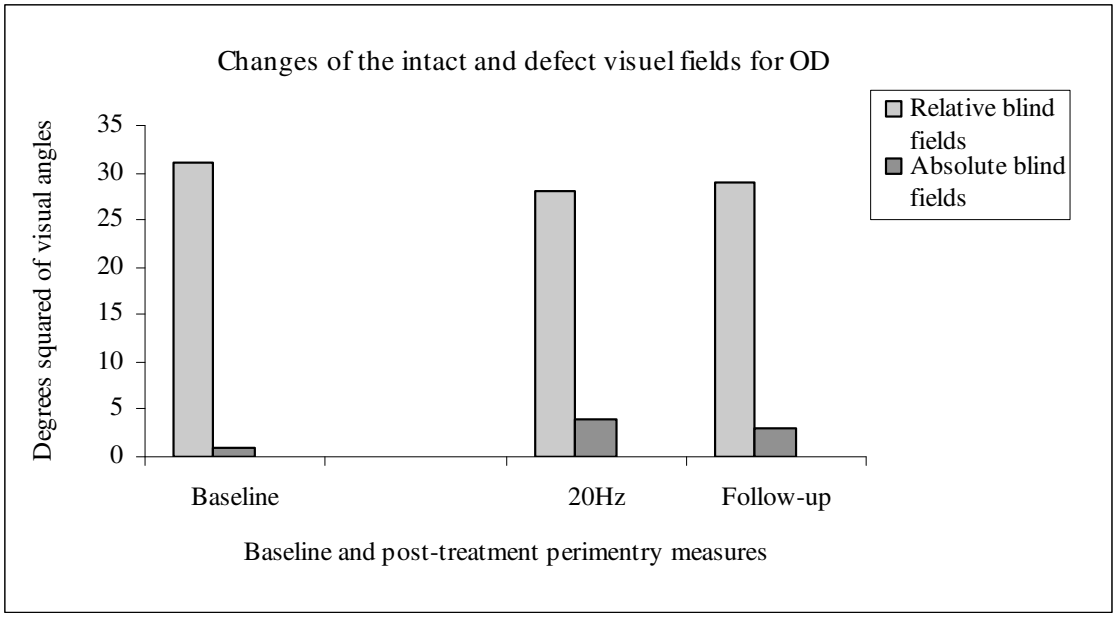
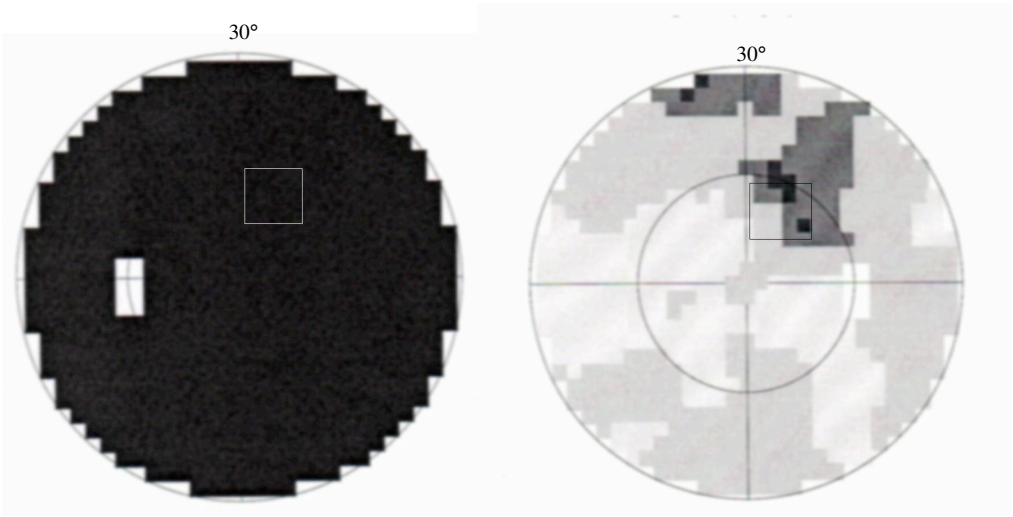



Figure 5.10: Patient FS (OD): Bars denote degrees² of visual angle for intact and defect fields in the transition zone. Results revealed for OD no changes in the size of the intact fields. The relative blind fields decreased following 20 Hz and after the one-hour break (follow-up measure), while absolute blind fields increased following 20 Hz and after the one-hour break (follow-up measure).

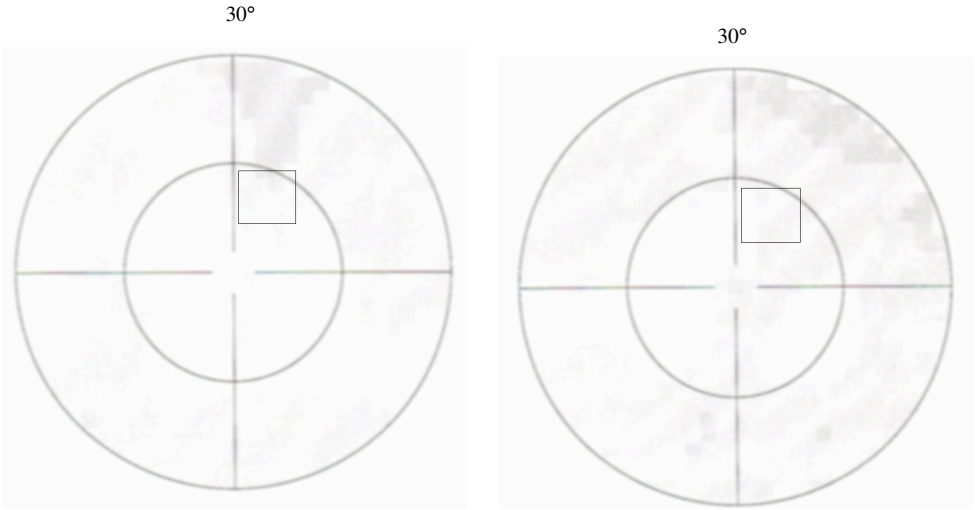
In summary the results revealed for OS an increase in the size of the intact fields following stimulation at 20 Hz and a decrease after the one-hour delay (the size of the intact fields was even less than that calculated for the baseline condition). There were no changes in the size of the relative blind fields following 20-Hz stimulation. After the one-hour break the size of the relative blind fields increased. The absolute blind fields decreased following 20-Hz stimulation and increased again after the one-hour break. For OD there was no enhancement of intact fields, but relative blind fields decreased following 20 Hz and were still decreased after the one-hour break, while absolute blind fields increased following 20 Hz and were still increased after the one-hour break.

Patient LE, Results of Experiment 5 (a)

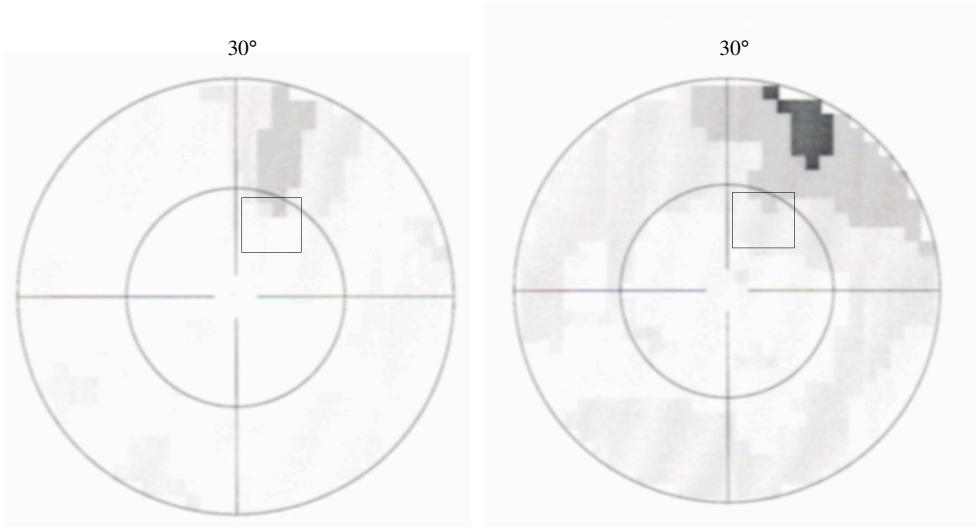
Nineteen days after determination of the baseline condition patient LE was examined. For the result of basic condition and post-treatment perimetry measures, with the marked stimulated area for Experiment 5 (a) in an overview:




(a): (OS) baseline condition (b): (OD)




(c): OD (20 Hz) (d): OD (27 Hz)




(e): OD (38 Hz) (f): OD (semi-static)

Figure 5.VII (a) and (b): Patient LE (OS and OD): The results of the baseline condition. Each rectangle represents 2°² of visual angle. The white rectangles signify the intact fields (i.e. fully functional) visual field(s), the grey signify the relative blind and the black rectangles signify the absolute blind field(s.). The white vertical rectangle symbolised the blind spot. The temporal stimulated area of 8° x 8°²of visual angle signifies the black rectangle. Results of intact and defect fields for OD after
(c) the 20-Hz stimulation, (d) the 27-Hz stimulation, (e) the 38-Hz stimulation and (f) the semi-static stimulation.

There are no results for OS, as patient LE is a complete blind on the left eye. As illustrated in Figure 5.11 results revealed for OD an increase of the size in the intact fields following all stimuli: 20 Hz (+ 27°² of visual angle), 38 Hz (+ 24°² of visual angle) and semi-static (+ 1°² of visual angle), with massive gain following stimulation at 27 Hz (+ 31°² of visual angle). Related to the relative blind fields, there is a decrease following all frequency stimuli: 20 Hz (- 21°² of visual angle), 27 Hz (- 25°² of visual angle) and 38 Hz (- 18°² of visual angle), with one exception of an increase following stimulation at semi-static (+ 5°² of visual angle). Related to absolute blind fields the results revealed a decrease following all frequency (20 Hz [- 6°² of visual angle], 27 Hz [- 6°² of visual angle] and 38 Hz [- 6°² of visual angle]). For all values see Table 5.7.

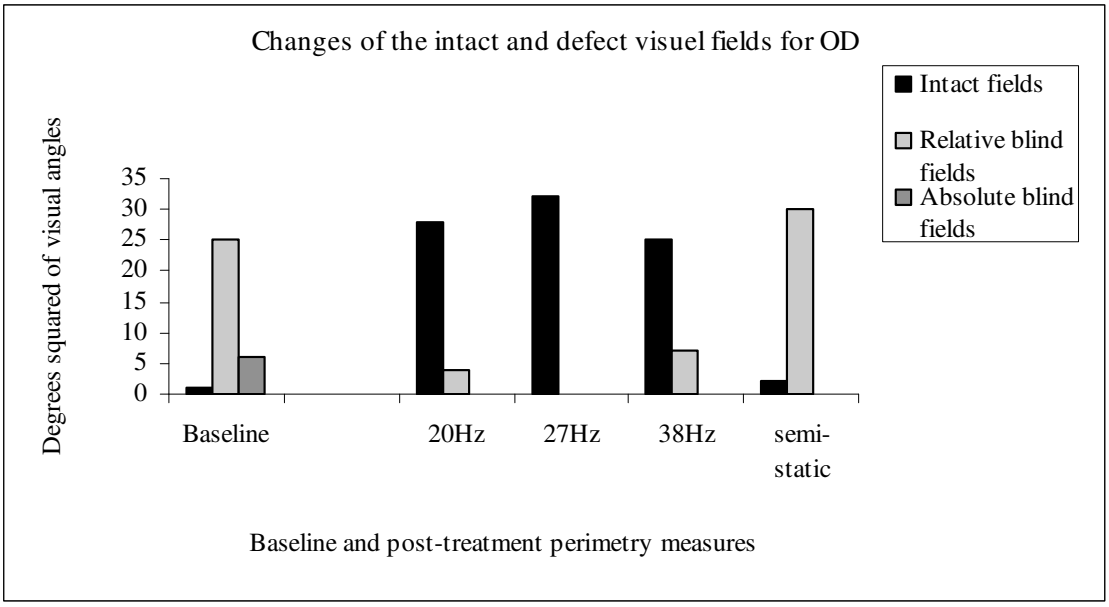



Figure 5.11: Patient LE (OD): Bars denote degrees² of visual angle for intact and defect fields in the transition zone. Results revealed an increase in the intact fields following all stimulations, with peak at 27 Hz. Relative blind fields decreased following all stimulations, with one exception of an increase following semi-static stimulation. Absolute blind field decreased following all stimulations.

Table 5.7: Patient LE (OD): Results of baseline condition and post-treatment measures.

| | OS | | | | | OD | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Degrees² of visual angle | | | | | Degrees² of visual angle | | | | |
| Fields of transition zone | Baseline | 20 Hz | 27 Hz | 38 Hz | semi-static | Baseline | 20 Hz | 27 Hz | 38 Hz | semi-static |
| Intact | 0 | 0 | 0 | 0 | 0 | 1 | 28 | 32 | 25 | 2 |
| Relative blind | 0 | 0 | 0 | 0 | 0 | 25 | 4 | 0 | 7 | 30 |
| Absolute blind | 32 | 32 | 32 | 32 | 32 | 6 | 0 | 0 | 0 | 0 |

Furthermore the calculated degrees² of visual angle for the intact and defect fields of the post-treatment measures were compared with the corresponding data given semi-static stimulation, as the semi-static stimulation is the experimental control condition.

Results revealed for OD an increase in the size of the intact field following all frequency stimulations (20 Hz [+ 26°² of visual angle], 27 Hz [+ 30°² of visual angle] and 38 Hz [+ 23°² of visual angle]). Accompanying this, the relative blind fields decreased following all frequency stimulations (20 Hz [- 26°² of visual angle], 27 Hz [- 30°² of visual angle] and 38 Hz [- 23°² of visual angle]). Absolute blind fields have not changed in comparison to the stimulation at semi-static (+/- 0°² all of visual angle). For all values see Table 5.7.

In summary in comparison to baseline condition and semi-static condition results revealed for OD an increase of size in the intact fields (with peak at 27-Hz stimulation) and minimal gain following semi-static stimulation. Accompanying this, the relative blind fields decreased in size following all frequency stimulations, with exception of an increase following semi-static stimulation. In comparison to the semi-static condition the

relative blind fields decreased. For the absolute blind fields results revealed a decrease following all stimulations.

## Discussion

The visual field morphology was examined using static visual field perimetry prior to and after patients were presented with a number of sessions of stimulation using a matrix of illuminated pixels presented at various frequencies (in square-wave and in case of RP additionally cosine-wave forms) to which patients had revealed a sensitivity in previous experiments (in particular, see Chapter III). In order to explore these mechanisms a dynamical experimental approach was applied in which time varying visual stimuli were employed that switched on and off in square-waves (additionally in case of patient RP cosine-waved) following 20-Hz, 27-Hz, 38-Hz and semi-static stimulation.

For patient RP results revealed in comparison to baseline condition and semi-static stimulation no changes in the size of the intact fields for OS, but an increase in OD following 38-Hz stimulation, due to both a shifting of relative and absolute blind fields. Furthermore for OS and OD changes in relative blind fields are associated with changes in the absolute blind fields; the increases and decreases changed with temporal and semi-static stimulation.

This was in accordance with Experiment 1 and 3 where patient RP was able to discriminate square-waved modulated stimuli at best given 38-Hz presentation (see Chapter III and IV). Additionally, in Experiment 1 patient RP provided the most commentaries on correct trials following 38-Hz presentation (see Chapter III). In contrast,

RP gave the most commentaries following 21-Hz, 27-Hz and 100-Hz presentations. Based on the results in Experiment 1 (and in respect that all patients tend to perform better given 38 Hz), it was concluded that responses to temporally modulated gratings seem to mediate blindsight performance at similar frequencies to those characterizing oscillatory synchronization during visual binding (e.g. Engel, König, Kreiter & Singer, 1991). Furthermore it has also been shown that internal feature coding mechanisms are entrainable by external stimulus modulation or in particular form-based processing can be influenced by synchronized stimuli presented in stimulus matrices that flicker at the same frequency as neurons synchronize in visual cortex (Elliott & Müller, 1998). Based on the ability of patient RP to show visual awareness and better form-discrimination at 38 Hz it can be reasoned that both are related to a mechanism that temporarily binds the relevant neurons together by synchronizing their spikes in 40-Hz oscillations (e.g. Crick & Koch, 1990a and 1990b, described in Koch, 2004). As morphological changes given square-waved stimuli reflect RP's better performance or sensitivity and her limited awareness of the stimuli, investigations using temporal stimulation can, in principle, show that lesions to the central visual system do not always result in a complete and permanent loss of function.

For patient RP the examination was repeated with cosine-waved stimuli.

These results revealed in comparison to baseline condition for OS an increase in the size of intact fields following 27 Hz and for OD an increase following 27 Hz, 38 Hz and with peak following semi-static stimulation. Furthermore for OS and OD the relative blind fields were reduced, with two exceptions of OS of an increase at semi-static stimulation and for OD at 27 Hz. Accompanying this, the absolute blind fields increased for OS and OD following all stimuli, with one exception for OS of a decrease at semi-

static stimulation and for OD of a decrease at 27 Hz. In comparison to semi-static stimulation, for OS the size of the intact fields increased following 27 Hz and for OD decreased following all frequency stimulations. The relative blind fields for OS decreased for all frequency stimulations, while for OD relative blind fields increased. Accompanying this, the absolute blind fields for OS increased for all frequency stimulations, while for OD absolute blind fields decreased following 27-Hz stimulation.

The enhancement for OS in the size of the intact fields at 27 Hz reflects the results of Experiment 2 where stimuli were cosine-ramped and where patient RP performed best given 27-Hz presentations (see Chapter III). Based upon the results of Experiment 5 (b) one can see that even when stimulated with cosine-waved stimuli, morphological changes in the size of the intact fields reflects results of discrimination performance shown in Experiment 2 (see Chapter III).

For patient FS, in comparison to baseline condition the results for OS showed that the size of the intact fields increased following stimulation at all frequencies, although the largest increase followed semi-static stimulation. The largest decrease in size was for the relative blind fields following 38 Hz and semi-static stimulation and the largest decrease in the absolute blind fields was found following 20-Hz and 27-Hz stimulation. In comparison to the baseline condition for OD the size of the intact fields increased given all frequency stimulations with the largest gain following 20-Hz presentation. There was a reduction in the size in the intact fields following semi-static stimulation, while decreases in the size of the relative blind fields were found following 20, 27 and 38 Hz. The largest decrease was found for the absolute blind fields given 20 Hz, 38 Hz and semi-static presentations. In comparison to the semi-static stimulation and for OS results revealed a

decrease in the size of intact fields following all frequency stimulations and for OD an increase following all frequency stimulations. For OS relative blind fields increased following all frequency stimulations and for OD decreased following all frequency stimulations. For OS absolute blind fields decreased following all frequency stimulations, with one exception of an increase given 38-Hz stimulation. For OD absolute blind fields did not change following all frequency stimulations, except of an increase given 27 Hz.

This was in contrast to Experiment 1 where FS performance was best given 38 Hz, followed by 21 Hz and 27 Hz (calculation with chi-square revealed FS to perform better at 25 Hz and best at 38 Hz). In Experiment 3 the results showed FS detected square-waved stimuli best at 38 Hz and 50 Hz.

In relation to the large enhancement for the intact fields in OD and following 20-Hz stimulation patient FS was examined in a further experiment by stimulating his transition zone at 27 Hz. This was done for examining a control condition and as 27 Hz revealed the least increase in the size of the intact fields. The results revealed no changes at all for OS. For OD there were no changes in the size of the intact fields following 27 Hz, but a decrease in the size of the relative blind fields and an increase in the size of the absolute blind fields. This was in accordance to Experiment 5 (a), where, for OD, less increase of the size of the intact fields was found following stimulation at 27 Hz. Interestingly, there were no changes at all for OS in the size of the intact and defect fields, while in Experiment 5 (a) the intact fields were less, but nevertheless still increased in size following 27-Hz stimulation.

In relation to the large enhancement for OD in the size of the intact fields following the 20-Hz stimulation Experiment 5 (a), in particular the 20-Hz stimulation was repeated and a follow-up static visual field perimetry measure was conducted after a one-hour

break (follow-up measure). This was aimed to examine a possible long-term effect of the increased size of the intact fields following 20-Hz stimulation. Results revealed for OS an increase in the size of the intact fields following stimulation at 20 Hz and a decrease after the one-hour delay (the size of the intact fields was even less than that calculated for the baseline condition). There were no changes in the size of the relative blind fields following 20-Hz stimulation. After the one-hour break the size of the relative blind fields increased. The absolute blind fields decreased following 20-Hz stimulation and increased again after the one-hour break. For OD there was no enhancement of intact fields, but relative blind fields decreased following 20 Hz and were still decreased after the one-hour break, while absolute blind fields increased following 20 Hz and were still increased after the one-hour break.

This is in contrast to Experiment 5 (a) where a large enhancement was found in the size of the intact fields when stimulated at 20 Hz. What's more is the conclusion that the size of intact fields increased when patient FS was stimulated at 38 Hz. This is in accordance with previous findings of patient FS performances (Experiment 1).

In conclusion, in Experiment 5 (b) there were no changes in the size of the intact fields following 27 Hz for OD, but a decrease in the size of the relative blind fields and an increase in the size of the absolute blind fields. This was in accordance with Experiment 5 (a), where a relatively small increase in the size of the intact fields was observed following stimulation at 27 Hz for OD. In Experiment 5 (c), the large increase of the size of the intact fields found for OD in Experiment 5 (a) could not be repeated, when stimulated at 20 Hz. However, for OS the size of the intact fields increased following stimulation at 20 Hz, but nevertheless examination conducted after the one-hour break revealed a reduction in the size of this gain (reduced to less than the baseline condition).

Therefore, one can infer that the effect of temporal stimulation is unstable- both for repeated measures (in the case of OD) and over time (in the case of OS and the follow-up measure).

For patient LE there are no results for OS, as he is completely blind in the left eye. For OD in comparison to baseline condition and semi-static condition results revealed an increase of size in the intact fields (with peak at 27-Hz stimulation) and minimal gain following semi-static stimulation. Accompanying this, the relative blind fields decreased in size following all frequency stimulations, with exception of an increase following semi-static stimulation. In comparison to the semi-static condition the relative blind fields decreased. For the absolute blind fields results revealed a decrease following all stimulations. In conclusion, for patient LE the size of the intact fields increased substantially in OD when stimulated at all frequencies and less so following semi-static presentations.

These results are in accordance with those found in Experiment 1, where patient LE discriminated square-waved modulated stimuli better when given intermittent stimulation (with the exceptions of stimulation at 21 Hz, 25 Hz and 71 Hz) and is in accordance with Experiment 3, where he detected stimuli better given 38 Hz (albeit worse performance than that following semi-static presentation). Due to his performance irrespective to temporal modulations it can be assumed in his case that in non-cortical cases, several optic fibres survive the effects of damage and that the blind area may be less dense than in the cortically blind patients, permitting some residual vision to occur. However, as the intact fields did not increase in size following semi-static stimulation, but did following temporal stimulation, it is possible that even if survived fibres lead to residual vision,

temporal modulation must further enhance that capability. Note that in his case the transition zone was overall of lesser magnitude (in terms of overall area) than for the two cortically blind patients (see Figure 5.VII).

In conclusion, for patient RP results of the size of the intact fields are in accordance with her tendency to respond found in previous findings (for square-waved given 38 Hz and semi-static and for cosine-waved given 27 Hz). Temporal stimulation leads indeed to a better 'sight'. However, for patient RP and LE morphology changes seem to be temporally specific (either with square- or cosine-waved modulated stimuli), as performance (and in the case of patient RP visual awareness) and changes in the intact field were approximately the same (see Chapter III). For patient FS there were enhancements in the size of the intact fields compatible to his results in previous findings, but not completely identical. However, in his case the results are difficult to interpret, as the enhancements might be due to a variety of reasons: patients with traumatic lesions, such as patient FS, are known to be invalid for static visual field perimetry measures as they can have fixation and attentional problems and the lesions have been found to lead to poor contrast detection. This conclusions follows from Horton (2005) who assumed that successful training is in reality just due to procedural artefacts such as an inability of maintain fixation and to keep the training stimuli in the blind field. In support of this point of view, Horton refers to Balliet, Blood and Bach-y-Rita (1985), who examined patients (homonymous hemianopic or quadrantanopic) with similar methods, but in which potential confounds resulting from poor fixation were controlled for. In their study the morphology of the visual field did not change.

In relation to all patients, even if the conducted static visual field perimetry measure can lead to these artefacts, during the training procedure fixation was maintained (for method see Chapter II) while the results are revealed at the same or similar frequencies to different types of enhanced visual capability revealed in previous experiments. In addition, it seems unlikely that poor fixation would be guided by any particular frequency – echoing Horton's charge that the visual system should not, in principle, be differentially influenced by a limited subset of the type of stimulation found in the natural visual environment. Note that in previous experiments, for all patients, stimuli were presented within the complete blind area. Furthermore for patient FS, it could be shown that change in visual field morphology is not easy to replicate and is not stable over time. This might be caused by artefacts due to patient FS lesion or on 'internal' induced artefacts (e.g. cortical metabolism, leading to changes in the particular frequency to which the system might be sensitive, Hoagland, 1966). This is in contrast to the prediction of Sabel and colleagues who have argued that rehabilitation and therefore stable effects of visual field are possible by training (VRT; e.g. for original report about VRT see Kasten & Sabel, 1995, described in Wüst et al., 2004) of the transition zone alone and are not subject to state variables – which might include cortical metabolism. However, even if the results are not stable, the transition zone of the patients is flexible, with measures of the relative and absolute blind fields not necessarily signifying absolute measures of damage and absence of function. The results also show that it is possible by external stimulation to enhance the size of intact fields and therefore promote an improvement in 'sighted ability'. Note that at the end in this study training effects were not examined as Sabel and colleagues did (Kasten et al., 1998; Kasten et al., 1999, Kasten et al., 2000, Wüst et al., 2004). For these examinations it might be necessary for patients to be trained at their

specific frequency for longer periods of time, such as VRT, which requires a training duration of 6 months and of at least 150 hours (1000 trials and one hour a day) – and which after this period still seems not to produce stable results. However, as the different patients show changes in the intact and blind fields when the transition zone is stimulated the results are in contrast to the assumption of Horton (2005) who claimed that training programmes reported to be effective for both monocular optic nerve diseases and homonymous, post-chiasmatic lesions are questionable, as there is no '…physiological mechanism that could explain improvement from the same treatments at different levels of the visual system' (Horton, 2005, p.1). One possible explanation of these findings for cortically as well as for a non-cortically blind patient might be that temporal stimulation (and in some cases even frequency specific stimulation), which might lead to a form of neuronal plasticity in the virtual sense (i.e. via a reconfiguration of the neuronal network underlying visual perception – the dynamic equilibrium mentioned earlier) and this may, following targeted training lead to more stable recovery. This remains an aim of future research. Furthermore the results support the idea of extrageniculostriate pathway mediating blindsight and that stimuli promoting transient neural responses tend to enhance blindsight performance more than those that do not promote this response; the extrageniculostriate pathway consists of residual retinal cell axons (magnocellular cells), which are known to provide high temporal frequency resolution and to generate a transient response to dynamic stimuli. However, in this context it should be mentioned that results of Experiment 5 (b, in patient RP) compatible results (even if more expressive [for OD]) as those revealed in Experiment 2, when stimulated with none transient stimuli.

In conclusion, the three examined patients, suffering of different lesions, which are of different age, while the patients themselves are of different age, showed morphology changes of the intact and defect fields when the transition zone is stimulated at frequencies to which patients had revealed some sensitivity in previous experiments.

The performance of patients using information just inside the transition zone leads to a good indication that the morphology of the visual-field defect can reduce with stimulation - a lesion in the central visual system does not always result in a complete and permanent loss of function (Zihl & von Cramon, 1979). The question remains of how to ensure the stability of this effect over time.

# Appendix

Chapter II:

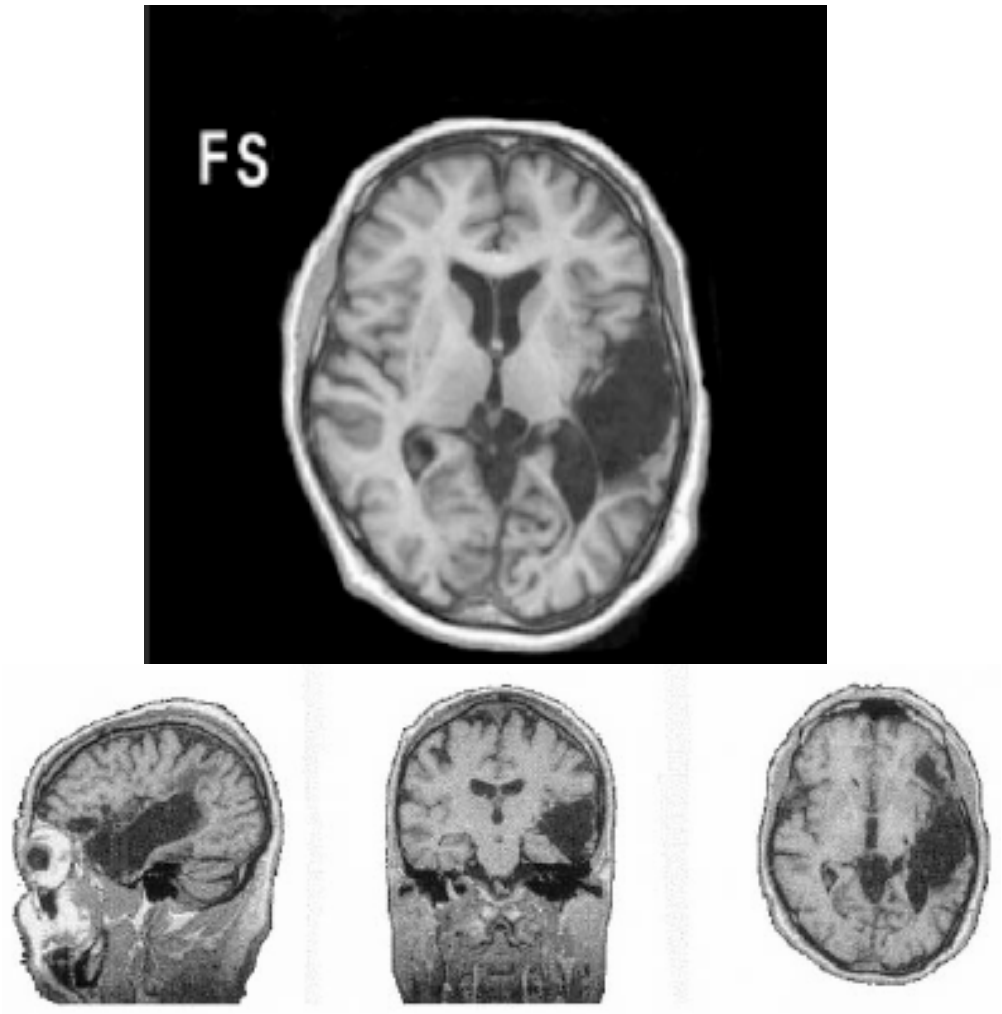



Image 1: MRI of patient FS. The lesion of the left hemisphere, caused as a result of a head injury form a road accident (which lead to a severe craniocerebral trauma), when he was at the age of 42. The resulting left hemispheric lesion extend from the base of the temporal lobe to parietal cortex (Stoerig, Kleinschmidt & Frahm, 1998, p. 22). The extensive lesion affects primarily the temporal lobe. 'The shape of his absolute defect as it now presents is characteristic of lesions of the LGN or the fibres (optic tract or radiation) in its vicinity. In FS, the lesion directly involves the optic radiation including Meyer's loop, which should have affected the LGN through retrograde degeneration.' (Kleiser, Wittsack, Niedeggen, Goebel & Stoerig, 2001, p. 655 and Van Buren, described in Kleiser et al., 2001, p. 655).

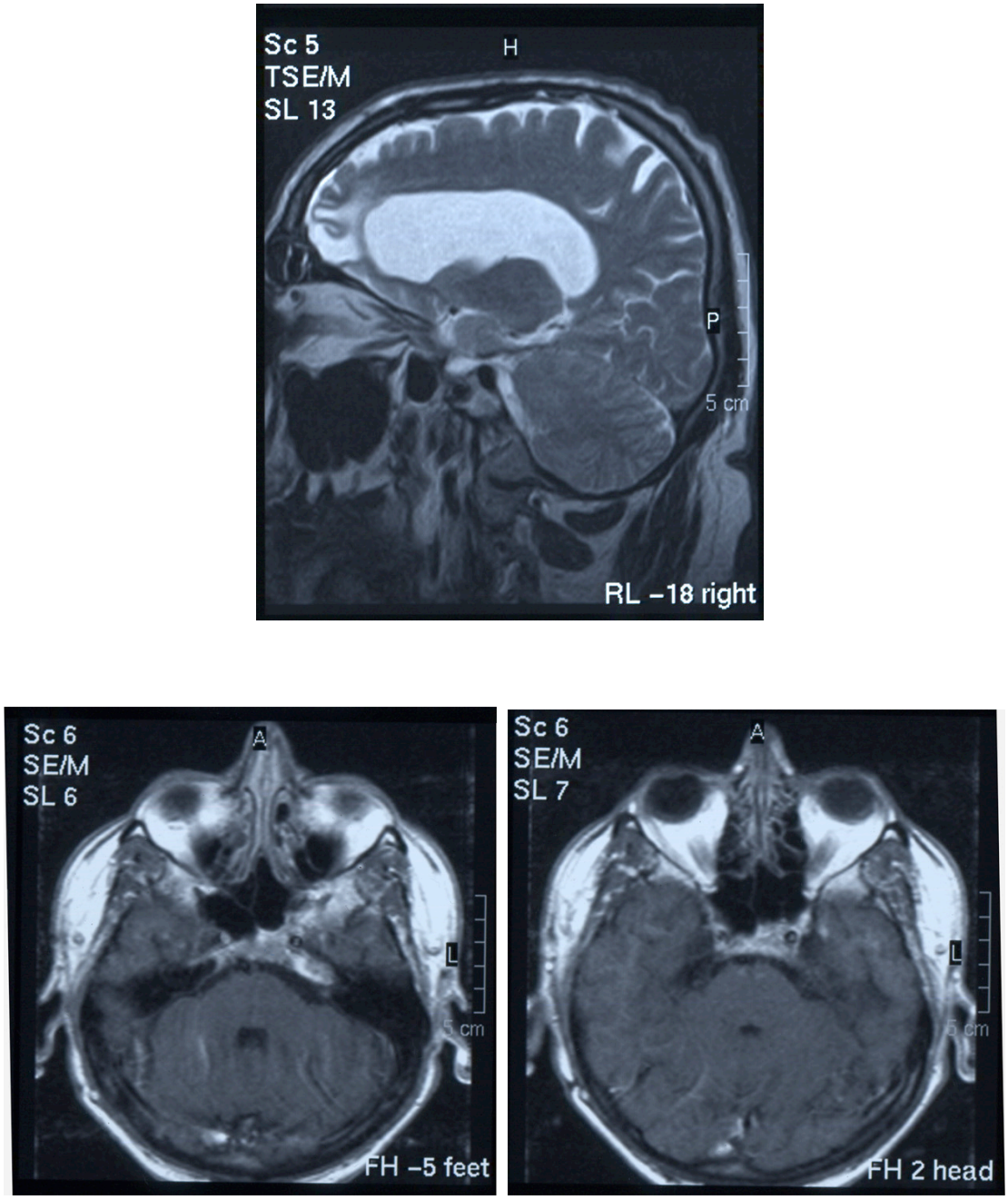



Image 2: MRI of patient LE. Surgery was conducted to remove a tumour located under the left optic nerve, when he was at the age of 46. The removed tumour obliterated the optic nerve and suppressed the optic chiasm.

## Chapter III:

Table of all commentaries of patient RP, FS and LE. Impressions where they had the feeling of noticing something 'brighter' were clustered as condition I, noticing something 'darker' were clustered as condition II, noticing something 'foggy' were clustered as condition III and noticing something 'figural' were clustered as condition IV.

| Experiment 1: All commentaries of patient RP, FS and LE. | | |
|---|---|---|
| Patient | Commentaries | Condition |
| RP | Hell, allgemein, diffus | I |
| | unten hell (jetzt größer) | I |
| | Alles heller, links (+ ganze Seite links) | I |
| | Ausschnitt, unten hell | I |
| | Rechts, schräg, wie hingeworfen | I |
| | Einfall von hinten | I |
| | / so rüber, ganz wenig, schräg | I |
| | Unten, dann kommt von oben | I |
| | Unten schräg hoch | I |
| | Kommt von rechts, schräg | I |
| | Jetzt oben Anflug | I |
| | Von rechts schräg runter | I |
| | Unten Eck | I |
| | Von rechts huscht / | I |
| | Hingeworfen | I |
| | | |
| | Ziemlich dunkel, ganz klein (bißchen mehr) | II |
| | Alles dunkler | II |
| | Von rechts, dunkel, durchsichtig | II |
| | Unten waagerecht, dunkel | II |
| | | |
| | Hauch | III |
| | Hauchig | III |
| | Hauch, wenig | III |
| | Hauchig, links unten | III |
| | Dahin geworfen, hauchig im Eck | III |
| | Wenig, unten Eck, hauchig | III |
| | Wie Kasten im linken Eck, milchig | III |
| | Hauch im Eck, unten | III |
| | Hauch von rechts /, schräg, von rechts | III |
| | Mitte, milchig | III |

| | | |
|---|---|---|
| | Von oben, hauchig | III |
| | Unten Hauch | III |
| | Andeutung, Hauch oben | III |
| | Von hinten | III |
| | Unten Ecke, Hauch, senkrecht | III |
| | Unten Eck, Hauch, 2 x Hauch nebeneinander | III |
| | Hauch, Mitte, links, schmaler Streifen | III |
| | | |
| | Streifen | IV |
| | Schmaler Streifen | IV |
| | 2 Streifen, durchsichtig | IV |
| | Diffus, Streifen | IV |
| | Von oben Streifen (von oben Streifen gerade + von oben 2 Streifen gerade) | IV |
| | Unten Eck, diffus | IV |
| | Links unten Streifen/Licht: unterschiedliche Nuancen in weiß; Wolle; klar bis zur Mitte hin | IV |
| | Unten Linien, Wolken (+ ……nach rechts) | IV |
| | 3 Fetzen nebeneinander, unten | IV |
| | Kegel, gesprenkelt | IV |
| | Sichel, unten, Mitte | IV |
| | Unten Eck, dünn, Kreis, hingeworfen | IV |
| | Hell, „Treppenform“ | IV |
| | | |
| FS | Noch dunkeler | II |
| | Mehr (dunkler) | II |
| | | |
| LE | ## | ## |

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# Deutsche Zusammenfassung (German Summary)

## Einleitung und Überblick

Läsionen des primären visuellen Kortex (V1) führen generell zu einem irreversiblen Gesichtsfeldausfall kontralateral zum geschädigten Bereich. Tatsächlich konnte aber gezeigt werden, dass es Patienten gibt, die trotz einer Läsion in V1, fähig sind Objekte, die ihnen im „blinden“ Gesichtsfeld präsentiert werden, überzufällig richtig zu unterscheiden, bzw. zu entdecken oder zu lokalisieren (z.B. Bard, 1905, described in Stoerig, 1999 und Weiskrantz, 2004; Riddoch, 1917; Humphrey, 1974; Weiskrantz, Warrington, Sanders & Marshall, 1974; Weiskrantz 1980). Diese Fähigkeit wird als visuelle Restkapazität bezeichnet, die sowohl mit einer visuellen Bewusstheit als auch ohne Bewusstheit einhergehen kann. Aufgrund dieses Unterschiedes hat Weiskrantz (Sanders, Warrington, Marshall & Weiskrantz, 1974 und Weiskrantz, 1986) den Begriff Blindsicht (englisch blindsight) als eine visuelle Restkapazität in Abwesenheit von Bewusstheit definiert. Patienten, die eine Blindsichtfähigkeit zeigen, können sich dieser dennoch bewusst werden, insofern ihnen ausreichend starke, d.h. hervorstechende Stimuli präsentiert werden. Patienten selbst beschreiben diese Bewusstheit als eine Art „Fühlen“ oder „Wissen“; zum Beispiel „fühlen“ bzw. wissen sie, dass ein präsentiertes „X“ „gezackt“ ist (Weiskrantz, Warrington, Sanders, & Marshall, 1974; Weiskrantz, 1986; Stoerig & Cowey, 1997). Patienten, die fähig sind Objekte zu beschreiben, bzw. diese während der Bearbeitung ihrer Aufgabe zu kommentieren, werden als Patienten angesehen, die eine Blindsichtfähigkeit mit

Bewusstheit zeigen, wobei sie per se nichts „sehen“ (z.B. Weiskrantz, 1986)[1]. Aufgrund dieser Blindsichtfähigkeit unterscheiden Trevethan und Sahraie (2003) zwischen Blindsicht I und Blinsicht II. Die erste beschreiben die Autoren als das Vorhandensein einer visuellen Restkapazität ohne Bewusstheit, letztere als das Vorhandensein einer visuellen mit Bewusstheit, aber ohne tatsächliche visuelle Wahrnehmung.

Aus anatomischer Sicht deuten einige Studien darauf hin, dass bei Blindsicht eine Aktivität in V1 als wahrscheinliche Quelle für visuelle Restkapazität ausgeschlossen werden kann und Blindsicht auf Aktivität im extrastriären Kortex basiert (Stoerig, Kleinschmidt & Frahm, 1998; Weiskrantz, 1996; Stoerig & Cowey, 1997; Stoerig, 2003), vermittelt durch den extrageniculaten Pfad (Mohler & Wurtz, 1977; Perenin, Ruel & Hecaen, 1980; Morris, DeGelder, Weiskrantz & Dolan, 2001).

Im Zusammenhang mit Blindsicht wurden auch die sogenannten neuronalen Korrelate der Bewußtheit („neuronal correlates of consciousness“, NCC) untersucht, wobei der Blindsicht mit visueller Bewusstheit Aktivierungen der extrastriären und präfontalen Kortizes zugeschrieben wurde (Sahraie, Weiskrantz, Barbur, Simmons, Williams & Brammer, 1997 und Zeki & Ffytche, 1998) und der Blindsicht ohne visueller Bewusstheit eher Aktivierungen sub-kortikaler Areale (Sahraie et al., 1997). Diese Annahmen passen zu denen von Crick und Koch (1995a und 1995b), die eine notwendige Aktivierung in V1 für visuelle Bewusstheit ausschließen und Bewusstheit ebenfalls auf eine Aktivierung der extrastriären und präfrontalen Kortizes zurückführen (Koch, 1994).

[1] Im Unterschied zu einer visuellen Restkapazität, die mit Bewusstheit einhergeht, können bei Patienten mit der Fähigkeit zur Blindsicht, diese mit beidem einhergehen: ohne und mit Bewusstheit. Sie negieren außerdem sich der präsentierten Stimuli bewusst zu sein. Bei Blindsicht mit Bewusstheit zeigen sich zudem funktionelle Unterschiede zur Blindsicht ohne Bewusstheit bezüglich Verarbeitung von Stimulusgeschwindigkeit, -verschiebung und -kontrast (Weiskrantz, Barbur & Sahraie, 1995).

Als möglichen Mechanismus für das Zustandekommen von visueller Bewusstheit nehmen Crick und Koch (1990a, 1990b, beschrieben in Koch, 2004) an, dass kortikale Mechanismen relevante Neuronengruppen durch eine Synchronisierung ihrer Aktivität „temporär binden“ (und die Feuerraten mit ca. 40 Hz oszillieren). Tatsächlich, und abgesehen von der Frage nach einem neuronalen Korrelat für Bewusstheit, konnten physiologische Studien zeigen, dass Neuronen als Antwort auf einzelne Merkmale einer selben Gestalt synchron im gamma-band Bereich (ca. 20 - 80 Hz) feuern (z.B. Engel, König, Kreiter & Singer, 1991). Dies kann als ein physiologisches Korrelat der „Bindung“ einzelner Objektmerkmale zu einer kohärenten (Objekt-) Repräsentation angesehen werden. Die theoretische Grundlage für „Bindung“ durch neuronale Oszillationen und Synchronisierung von Feuerraten basiert auf den theoretischen Annahmen von von der Malsburg (z.B. 1981, 1985; von der Malsburg & Schneider, 1986; Gray & Singer, 1989). Spätere Untersuchungen konnten zeigen, dass diese Bindungsmechanismen durch externe Stimulation, d.h. durch Stimuli die im gamma-band Bereich flickern, beeinflusst bzw. unterstützt werden können (z.B. Elliott & Müller, 1998). Des Weiteren wurde unzureichende, „geschädigte“ Synchronizität als Grund für Wahrnehmungsdefizite angesehen (z.B. Singer, 1999; Vanni, Raninen, Näsänen, Tanskanen und Hyvärinen, 2001). In einer Einzelfallstudie konnten Vanni und Kollegen anhand von MEG Aufnahmen zeigen, dass ihr Patient, der sinusoidal flickernde Muster zu entdecken hatte, einen abnormalen Verlauf der Hirnaktivität zeigte. Im Speziellen fanden sie heraus, dass Stimuli in der betroffenen Gesichtsfeldhälfte keine frühe, transiente Aktivität in posterioren parietalen Regionen generierten, aber eine spätere und relativ starke Aktivität in kontralateralen superior-temporalen (ST) Regionen. Die Autoren schlossen daraus, dass der Mangel an früher,

posterior synchronisierter neuronaler Aktivität verantwortlich ist für die verstärkte Aktivität mit längerer Latenz in ST Arealen und deshalb eine Kompensierung des gestörten Inputs durch höhere Prozesse für die Restkapazität im betroffenen Gesichtsfeld notwendig sein könnte (Vanni et al., 2001, S. 865).

Die Autoren schlossen daraus, dass ein geschädigter V1 durch „höhere Prozesse" kompensiert wird, was zu einer visuellen Restkapazität im blinden Gesichtsfeld führt.

Obwohl es eine Vielzahl von Studien über Blindsicht gibt, wurden die temporalen Mechanismen, die dabei eine Rolle spielen könnten, bisher kaum untersucht. Weiskrantz sowie Sahraie, Weiskrantz, Trevethan, Cruce und Murray (1986; 2002, beschrieben in Trevethan & Sahraie, 2003) zeigten, dass die Leistung Objekte (Gitter) zu entdecken besser ausfiel, wenn diese flickerten (relativ zu statisch dargebotenen Objekten). Trevethan und Sahraie (2003) fanden zudem heraus, dass sich die Blindsichtfähigkeit steigern lies, wenn Objekte mit Frequenzen zwischen 10 - 33 Hz (sinusmoduliert) dargeboten wurden (die beste Leistung lag dabei bei 20 Hz); diese Ergebnisse passen zu denen von Barbur, Harlow und Weiskrantz (1994), die eine Steigerung der Blindsichtfähigkeit bei der Präsentation sinusmodulierter Stimuli zwischen ~ 6 - 40 Hz fanden[2].

Neben solchen Ergebnissen wurde auch angenommen, dass die Ausdehnung eines Gesichtsfelddefektes durch Training verringert werden kann und somit eine Läsion des zentralen visuellen Systems nicht unbedingt zu einem kompletten und permanenten Funktionsverlust führen muss (Zihl & von Cramon, 1979 und 1985). Trainingsmethoden wie VRT („Visual Restoration Therapy"; Näheres über VRT siehe Kasten & Sabel, 1995) konnten zeigen, dass ein Training der Übergangszone (d.h. des

[2] Trevethan und Sahraie (2003) fanden zusätzlich in den experimentellen Bedingungen auch eine „erhöhte" visuelle Bewusstheit.

Bereichs in dem intakte, relative und absolut blinde Felder ineinander übergehen) möglich ist und zu einem Gewinn von Sehgradwinkeln des intakten Gesichtsfeldbereich in der Übergangszone führt (Kasten, Wüst, Behrens-Baumann & Sabel, 1998; Kasten, Poggel, Muller-Oehring, Gothe, Schulte & Sabel, 1999; Kasten, Poggel & Sabel, 2000; Wüst, Kasten & Sabel, 2004).

Aufgrund dieser Befunde wurde in der vorliegenden Studie untersucht, ob sich die Blindsichtfähigkeit durch Stimuli, die im gamma-band Bereich flickern steigern lässt. Es wurde angenommen, dass die an der Studie teilnehmenden Patienten die dargebotenen Stimuli besser unterscheiden sowie entdecken können, wenn diese schnell an/aus („square-waved“) alternieren oder kosinusmoduliert sind. Des Weiteren wurde untersucht ob die Patienten neben ihrer Fähigkeit überzufällig gut Stimuli zu erraten, diese auch „fühlen“, d.h. ob sie fähig sind eine visuelle Bewusstheit zu zeigen. In einem weiteren Experiment wurde untersucht, ob sich die Morphologie in der Übergangszone verändert, wenn diese temporal stimuliert wird. Die Stimulation wurde dabei in Frequenzen durchgeführt, bei denen die Patienten in den vorhergehenden Untersuchungen eine erhöhte Blindsichtfähigkeit gezeigt haben. Es wurde erwartet, dass durch die Stimulation die Sehwinkelgrade der intakten Felder in der Übergangszone zunehmen werden.

Methode

An dieser Studie nahmen eine weibliche und zwei männliche Patienten teil. Die weibliche Patientin (RP) leidet aufgrund eines Schlaganfalls (linker Okzipitallappen) an einer oberen rechten homonymen Quandrantenanopsie, wobei die defekten Felder in die unteren rechten Quadranten übergehen; mit Aussparung der Makular: (OS) 14.25°² und (OD) 12.25°² Sehgradwinkel (Experiment 5 [OS] 18.25°² und [OD] 12.25°² Sehgradwinkel). Der erste männliche Patient (FS) leidet aufgrund eines Schädel-Hirn-Traumas an einer rechten, inkompletten, homonymen Hemianopsie (Experiment 5: komplette rechte Hemianopsie mit zusätzlich relativen (d.h. nicht komplett blinden) Defekten im oberen und unteren linken Teil des Gesichtfeldes). Der zweite männliche Patient (LE) leidet an einem Gesichtsfeldausfall, der nicht auf eine kortikale Schädigung beruht. Bei ihm wurde ein Tumor entfernt, der unterhalb des linken Nervus Opticus lag, was zu einer linksseitigen Hemianopsie führte (Experiment 5: komplette Erblindung im linken Auge [OS] und einzelne defekte Felder im rechten Auge [OD]).

Zu Beginn der Studie wurde für jeden Patienten, beruhend auf Perimetriemessungen, berechnet, wo im Gesichtsfeld die Stimuli präsentiert werden müssen, damit sie in den absolut defekten Gesichtsfeldbereich fallen.

Um die temporalen Mechanismen zu untersuchen wurden die Stimuli in Experiment 1 und 3 (Kapitel III und IV) mit einer „square-wave“-artigen Modulation in folgenden Frequenzen dargeboten: 20, 21, 25, 27, 33, 38, 50, 71 und 100 Hz. In Experiment 2 und 4 hingegen handelte es sich um eine Kosinusmodulation der Stimuli, die in folgenden Frequenzen dargeboten wurden: 19, 21, 24, 27, 31, 38, 47, 62 und 90 Hz (Kapitel III und IV). In Experiment 1 und 2 waren die Patienten angehalten vier verschiedene Richtungen der Stimuli zu unterscheiden und in Experiment 3 und 4

Stimuli zu entdecken, die aus kontinuierlichen oder unterbrochenen Linienmustern bestanden. Die Entdeckungsaufgabe beinhaltete dabei eine Konfidenzschätzung. Im Allgemeinen sollten die Patienten die Stimuli erraten und ihre Antworten kommentieren. Letzteres sollte dazu dienen die visuelle Bewusstheit der Patienten zu erfassen. In Experiment 5 wurden, basierend auf den Ergebnissen von Experiment 1, 2, 3 und 4, in der Übergangszone jedes Patienten Stimuli präsentiert, die entweder statisch oder in einer Flickerfrequenz von 20, 27 oder 38 Hz dargeboten wurden.

## Kapitel II: Ergebnisse und Schlußfolgerungen

Alle Patienten nahmen an einem klassischen Blindsicht Experiment teil[3], bei dem ihnen im defekten Gesichtsfeld unterschiedlich orientierte Stimuli präsentiert wurden, die sie zu unterscheiden hatten. Diese Stimuli, die auch in Experiment 1 und 2 dargeboten wurden, waren hier nicht temporal moduliert und es gab zusätzlich die Bedingung, dass kein Stimulus dargeboten wurde. Die Resultate ergaben, dass keiner der Patienten fähig war die Art der Stimuli signifikant überzufällig zu unterscheiden. Die Patienten RP und LE waren jedoch in der Lage die Präsenz der Stimuli von der Abwesenheit der Stimuli zu unterscheiden. Alle Patienten zeigten allerdings eine Art visueller Erfahrung.

Zusätzlich wurde ein Kontrollexperiment durchgeführt, in welchem die gleichen Stimuli wieder dargeboten wurden, diesmal jedoch im intakten Gesichtsfeldbereich. Es zeigte sich, dass alle Patienten fähig waren die Stimuli zu unterscheiden, woraus sich

[3] Hiermit ist eine „forced-choice“ Methode gemeint, die im Allgemeinen als die „klassische“ Methode zur Erfassung einer Blindsichtfähigkeit herangezogen wird (z.B. Weiskrantz, 1986).

schließen lässt, dass alle Patienten fähig waren ihre Vigilanz zu halten, bzw. fähig Stimuli zu unterscheiden und Entscheidungen zu fällen.

Zudem wurde mit den Patienten ein Neglect-Test („Behavioural inattention test manual“, BIT) und ein Intelligenztest (Mehrfachwahl-Wortschatz-Intelligenz-Test, MWT-B) durchgeführt, da Blindsicht oftmals mit Aufmerksamkeitsproblemen der Patienten assoziiert wird und verbale sowie kognitive Unterschiede ausgeschlossen werden sollten. Keiner der Patienten zeigte einen visuellen Neglect. Die Intelligenztests ergaben einen IQ von über 100 Punkten für alle Patienten, was ein Indiz dafür ist, dass die Patienten keine Probleme hatten die ihnen gestellten Aufgaben zu verstehen und durchzuführen bzw. ihre Entscheidung verbal zu kommunizieren.

## Kapitel III: Ergebnisse und Schlussfolgerungen

Prozent-korrekt und Chi-Quadrat Analysen der Daten von Experiment 1 ergaben, dass alle Patienten generell fähig waren die ihnen dargebotenen Objekte zu unterscheiden, wenn diese temporal moduliert waren, wobei sie besonders gute Leistung bei 38 Hz zeigten (im Falle von Patient LE waren die Leistungen auch bei 20 Hz und 100 Hz gut). Des Weiteren konnte die Patientin RP ihre Entscheidungen zusätzlich kommentieren, d.h. sie zeigte also eine Art visueller Bewusstheit und wurde deswegen als Blindsicht II (siehe Trevethan & Sahraie, 2003) kategorisiert. Ihre Leistung bezüglich korrekter Antworten und Anzahl von Kommentaren der Gruppe 1 („brigther“ Bedingung), war besonders gut, wenn die Stimuli mit 38 Hz flickerten.

Aus diesen Ergebnissen kann man schließen, dass die temporale Modulation von Stimuli die Fähigkeit zur Blindsicht fördert und zwar dann, wenn diese mit Frequenzen

im gamma-band Bereich dargeboten werden, die im Allgemeinen mit Objekt-/Merkmals-Bindung in Zusammenhang gebracht werden (z.B. von der Malsburg, 1981, 1985; Singer & Gray, 1989; Engel, König, Kreiter & Singer, 1991). Die Ergebnisse bestätigen auch die Befunde, dass kortikale Mechanismen tatsächlich durch externe (gamma-band frequente) Stimulation beeinflusst werden können (z.B. Elliott & Müller, 1998). Darüber hinaus findet die Vorstellung von Crick und Koch (1990a, 1990b, beschrieben in Koch, 2004), dass Bewusstsein durch temporär synchronisiertes Feuern von Neuronengruppen (mit etwa 40 Hz) zustande kommt, durch die Ergebnisse von Patientin RP Unterstützung.

Die Ergebnisse aus Experiment 2 ergaben für die beiden kortikal blinden Patienten RP und FS keine signifikant bessere Leistung, wenn die Stimuli kosinusmoduliert waren. Interessanterweise zeigten aber beide Patienten einen ähnlichen Trend und die beste Leistung bei 27 Hz. Hingegen zeigte Patient LE eine signifikant bessere Leistung bei allen temporalen Stimulierungen (und auch eine signifikante Leistungssteigerung bei der statischen Bedingung); besonders hoch war seine Leistung bei 21 Hz und 90 Hz.

Im Vergleich zu den Ergebnissen aus Experiment 1 können die Resultate aus Experiment 2 damit erklärt werden, dass die Stimuli in Experiment 2 kosinusmoduliert waren. Dabei senden diese ein schwächeres Signal aus als die „square-waved“ modulierten Stimuli. Dies könnte auch der Grund dafür sein, dass Patientin RP ihre Antworten diesmal nicht kommentieren konnte. Bezogen auf Patient LE, der die beste Leistung bei 20 Hz zeigte und relativ zur Leistung der anderen Patienten in Experiment 2, sind die Ergebnisse kompatibel mit denen von Trevethan und Sahraie (2003), die herausfanden, dass sich die Blindsichtfähigkeit steigern lies, wenn Objekte mit

Frequenzen zwischen 10 - 33 Hz (sinusmoduliert) dargeboten wurden (die beste Leistung lag dabei bei 20 Hz).

Obwohl es Unterschiede zwischen den Ergebnissen in Experiment 1 und 2 gab, zeigten beide Experimente jeweils einen ähnlichen Trend der beiden kortikal blinden Patienten. Diese Trends unterschieden sich von dem des nicht-kortikalen Patienten LE, welcher bei fast allen temporalen Stimulierungen eine bessere Leistung zeigte. Dies könnte bei ihm auf nicht beschädigte Axone des Nervus Opticus hindeuten, welche eine generell erhöhte visuelle Restkapazität ermöglichen könnten.

Die Ergebnisse unterstützen des Weiteren die Annahme, dass die Fähigkeit zur Blindsicht über den extrageniculaten Pfad vermittelt wird (z.B. Perenin & Jeannerod, 1978), da es vor allen Dingen in Experiment 1, in dem die Stimuli „square-waved" moduliert waren, zu einer Erhöhung der Blindsichtleistung kam, und der extrageniculate Pfad, aus magnozellulären Zellen besteht, welche dafür bekannt sind, dass sie eine hohe zeitliche Auflösung (im Sinne ihrer Feuerfrequenz) haben und transiente Aktivität als Antwort auf solche Stimuli zeigen.

## Kapitel IV: Ergebnisse und Schlussfolgerungen

Die Daten von Experiment 3 und 4 wurden mittels Parameter aus der Signalentdeckungstheorie ausgewertet und ergaben weder für Experiment 3 noch für Experiment 4 signifikante Ergebnisse.

Nichtsdestotrotz zeigten die Patienten eine leicht besser Entdeckungsleistung in Experiment 3 bei 38 Hz (sowie bei 71 Hz bei Patientin RP und bei 50 Hz Patient FS).

Interessanterweise konnte Patient LE bei keiner temporalen Stimulation ein besseres Ergebnis erreichen relativ zur Darbietung von Stimuli ohne Flicker.

Die Ergebnisse aus Experiment 4 zeigten für die Patientin RP eine bessere Entdeckungsleistung wenn die Stimuli bei 24, 38, 47 und 62 Hz präsentiert wurden. Patient FS konnte bei flickernden Stimuli keine Ergebnisse über das Zufallsniveau hinaus zeigen; seine Leistung bei 47 Hz war allerdings schlechter als bei den anderen temporalen Stimulationen. Dies könnte jedoch auf einen systematischen Fehler im Antwortverhalten basieren. Seine Leistungen bezüglich der temporalen Stimulationen waren insgesamt aber besser als die, die er bei den statischen Stimuli zeigte. Die Ergebnisse für Patient LE ergaben, dass er diesmal im Vergleich zu Experiment 3 bei 38 Hz eine bessere Leistung zeigte als bei den statisch präsentierten Stimuli. Insgesamt war seine Leistung bei den temporalen Stimuli allerdings wieder schlechter als bei der statischen Stimulation. Bei 47 Hz zeigte er außerdem die gleiche, schlechtere Leistung wie Patient FS. Im Allgemeinen ergaben die Ergebnisse aus Experiment 3 und 4 ungefähr den gleichen Trend für Patient FS und LE. Dies ist insofern interessant, da aufgrund der Ergebnisse aus Experiment 1 und 2 angenommen wurde, dass die Ergebnisse von Patient LE durch (aufgrund seiner Läsion) „nicht beschädigte Axone“, beeinflusst gewesen sein könnten und er sich deswegen von den kortikal blinden Patienten unterscheidet. Da hier allerdings ein ähnlicher Trend zwischen einem kortikal blinden Patienten, nämlich Patient FS und dem nicht-kortikal blinden Patienten LE aufgezeigt wurde, kann man die Ergebnisse von Patient LE nicht mehr unbedingt nur auf solche „nicht-beschädigten“ Axone zurückführen.

Zusammenfassend hat nur Patientin RP (die sich von Patient FS und LE unterschied) eine Leistung gezeigt, die der in Experiment 1 entsprach.

Interessanterweise und im Vergleich zu Experiment 1 zeigten alle Patienten eine bessere Leistung Stimuli zu unterscheiden als sie zu entdecken. Dieser Unterschied könnte auf den verschiedenartigen Stimuli beruhen, die in den Experimenten dargeboten wurden. Die Entdeckung einer kleinen Linienunterbrechung benötigt einfach mehr lokale visuo-kortikale Mechanismen, deren Chance eine Läsion zu überleben sehr gering ist oder die durch Aktivität in anderen unterstützenden Verbindungen überspielt werden. Dies deutet auf einen extrastriären Entstehungsort für die Effekte aus Experiment 1 und 2 hin, möglicherweise durch "form-from-motion" Kodierungsmechanismen in V3 oder V5 beispielsweise.

## Kapitel V: Ergebnisse und Schlussfolgerungen

### Patient RP: Experiment 5(a)

Die Datensätze von Experiment 5 wurden wie folgt ausgewertet: Zuerst wurde für jeden Patienten eine Perimetriemessung (Baseline Messung) durchgeführt, um die individuelle Übergangszone (d.h. der Bereich in dem intakte, relative und absolut blinde Felder ineinander übergehen) zu lokalisieren und die Sehwinkelgrade der intakten, relativ und absolut blinden Felder zu berechnen (in diesem Fall aufzusummieren). Ein Teil der Übergangzone wurde dann in Frequenzen stimuliert, bei denen die Patienten in den vorherigen Experimenten eine besondere (gute) Leistung gezeigt haben (20-Hz, 27-Hz, 38-Hz und ohne Flicker). Die Stimulationen der „square-waved" modulierten Stimuli (und im Falle von Patientin RP zusätzlich kosinusmodulierten Stimuli) erfolgten nacheinander, wobei nach jeder einzelnen Stimulation eine weitere Perimetriemessungen („Post-treatment" Messung) durchgeführt wurde, so dass die

Sehwinkelgrade der intakten und defekten Felder (für jedes Auge getrennt: linkes Auge [OS] und rechtes Auge [OD]) nach der Stimulation des Teiles aus der Übergangszone mit dem berechneten Feldern der Baseline Messung verglichen werden konnten. Zusätzlich wurde die Größe der intakten und defekten Felder nach der temporalen Stimulation mit ihrer Größe nach der statischen Präsentation verglichen.

Der Vergleich zwischen Baseline Messung und Post-treatment Messungen sowie dem Vergleich zwischen statischer und temporaler Stimulation ergaben für das linke Auge (OS) der Patientin RP keine Veränderung der Sehrgradwinkel der intakten Felder und für das rechte Auge (OD) eine Zunahme nach der 38-Hz Stimulation. Dementsprechend nahmen die defekten Felder in ihrer Größe ab. Dieses Ergebnis ist konsistent mit denen die in Experiment 1 und 3 bei Patientin RP gefunden wurden. In diesen Experimenten zeigte sie eine bessere Leistung sowie eine „erhöhte“ visuelle Bewusstheit, wenn die Stimuli mit 38 Hz präsentiert wurden (siehe Kapitel III). Aufgrund dessen kann angenommen werden, dass kortikale Läsionen nicht notwendigerweise zu einem kompletten, permanenten Verlust der visuellen Funktion führen müssen (Zihl & von Cramon, 1979). Das Ergebnis in Experiment 5 (a) spiegelt dabei die morphologischen Veränderungen der guten Leistung und Sensitivität von Patientin RP in den vorherigen Experimenten wider (vor allen Dingen von Experiment 1).

Experiment 5 (a) wurde für die Patientin RP wiederholt, wobei die Stimuli dabei konsinusmoduliert waren.

Patient RP: Experiment 5(b)

Die Ergebnisse der Stimulation mit kosinusmodulierten Stimuli ergaben für OS eine Zunahme der Sehgradwinkel der intakten Felder nach der 27-Hz Stimulation und für OD eine Zunahme nach der 27-Hz, 38-Hz und statischen Stimulation. Die relativ blinden Felder nahmen für OS und OD generell ab, wobei für OS die relativ blinden Felder nach der statischen Stimulation und für OD nach der 27-Hz Stimulation zunahmen. Dementsprechend nahmen die absolut blinden Felder für OS und OD zu, wobei für OS die absolut blinden Felder nach der statischen Stimulation und für OD nach der 27-Hz Stimulation abnahmen. Im Vergleich zur statischen Stimulation konnten für OS eine Zunahme der intakten Felder nach der 27-Hz Stimulation beobachtet werden und eine Abnahme für OD nach allen temporalen Stimulationen (20 Hz, 27 Hz und 38 Hz). Während für OS die Sehgradwinkel relativ blinder Felder nach allen temporalen Stimulationen abnahmen, nahmen sie für OD zu. Dementsprechend nahmen die absolut blinden Felder für OS nach allen temporalen Stimulationen zu; im OD blieben die absolut blinden Felder im Vergleich zur statischen Stimulation gleich und nahmen nur nach der 27-Hz Stimulation ab.

Die Zunahme der intakten Felder im OS nach der 27-Hz Stimulation entspricht dem Ergebnis in Experiment 2 (siehe Chapter IV), welches aufzeigte, dass die Patientin RP die beste Leistung erzielt, wenn die Stimuli mit 27 Hz präsentiert werden. Daraus kann geschlossen werden, dass selbst wenn die Stimuli kosinusmoduliert waren, die morphologischen Veränderungen die der Unterscheidungsleistung widerspiegeln (siehe Kapitel III).

Patient FS: Experiment 5(a)

Der Vergleich zwischen Baseline Messung und Post-treatment Messungen ergab für Patient FS für OS sowie OD eine Zunahme der intakten Felder nach allen temporalen Stimulationen, wobei für OS die größte Zunahme an Sehgradwinkeln nach der statischen Stimulation beobachtet werden konnte und für OD eine besonders große nach der 20-Hz Stimulation zu finden war. Für OS konnte die größte Abnahme der relativ blinden Felder nach der 38-Hz und statischen Stimulation und für die absolut blinden Felder nach der 20-Hz und 27-Hz Stimulation beobachtet werden. Für OD ergaben die Berechnungen der Sehgradwinkel eine Abnahme der relativ blinden Felder nach allen temporalen und eine Zunahme nach der statischen Stimulation. Die größte Abnahme der absolut binden Felder konnte für OD nach der 20-Hz, 38-Hz und statischen Präsentation gefunden werden.

Bezogen auf die intakten Felder entsprachen die Ergebnisse nicht denen aus den vorherigen Experimenten, vor Allem nicht denen aus Experiment 1 (hier zeigte Patient FS die beste Leistung wenn die „square-waved“ modulierten Stimuli bei 38 Hz präsentiert wurden).

Aufgrund der großen Zunahme der intakten Felder für OD nach 20-Hz Stimulation wurde in einem weiteren Experiment Patient FS mit 27-Hz stimuliert (als eine Art Kontrollexperiment), da hier die niedrigste Zunahme an intakten Feldern zu finden war.

Patient FS: Experiment 5(b)

Für OS ergaben die Berechnungen der intakten und defekten Felder keine Veränderungen. Für OD konnte zwar keine Veränderung der Sehrgradwinkel für die intakten Felder nach der 27-Hz Präsentation gefunden werden, aber eine Abnahme der relativ blinden und eine Zunahme der absolut blinden Felder.

Dies entsprach den Ergebnissen aus Experiment 5(a), bei denen für OD nur ein leichter Anstieg der intakten Felder nach der 27-Hz Stimulation gefunden werden konnte.

In einem dritten Experiment wurde die Übergangszone von Patient FS's Gesichtfeldes dann noch einmal mit 20 Hz stimuliert um zu untersuchen, ob der gefundene Gewinn an intakten Feldern in Experiment 5(a) zu wiederholen ist. Zusätzlich wurde eine Follow-up Messung vorgenommen. Diese erfolgte nach einer Stunde Pause und diente zur Erfassung, ob der Gewinn an intakten Feldern über die Zeit stabil bleiben kann.

Patient FS: Experiment 5(c)

Die Ergebnisse ergaben diesmal eine Zunahme der Sehgradwinkel der intakten Felder für OS nach der 20-Hz Stimulation und eine Abnahme dieser gewonnenen intakten Felder nach einer Stunde Pause (Follow-up Messung). Bezogen auf die relativ blinden Felder ergaben sich keine Veränderungen nach der 20-Hz Stimulation; allerdings nahmen sie nach einer Stunde Pause zu. Die absolut blinden Felder waren nach der 20-Hz Stimulation reduziert und stiegen nach einer Stunde Pause wieder an. Für OD ergaben die Berechnungen diesmal keinen Gewinn an intakten Feldern; die

relativ blinden nahmen nach der 20-Hz Stimulation ab und blieben auch noch nach einer Stunde Pause reduziert. Dementsprechend stiegen die absolut blinden Felder nach der 20-Hz Stimulation an und blieben es noch leicht nach einer Stunde Pause.

Da in Experiment 5(a) ein großer Zugewinn an intakten Feldern nach der 20-Hz Stimulation für OD gefunden werden konnte und in Experiment 5 (c) nicht, sind die Effekte einer temporalen Stimulierung vermutlich über die Zeit hinweg instabil.

Es sollte hier angemerkt werden, dass Schwankungen bzw. unterschiedliche Ergebnisse von Perimetriemessungen bei Schädel-Hirn-Trauma Patienten nicht untypisch sind.

Patient LE: Experiment 5(a)

Die Ergebnisse von Patient LE zeigten, dass er auf dem linken Auge komplett blind geworden ist. Es gab deswegen keine Ergebnisse für OS. Der Vergleich mit der Baseline Messung und statischen Stimulation hat für OD einen Zugewinn der intakten Felder ergeben, wobei die größten Zunahme nach der 27-Hz und die kleinste Zunahme nach der statischen Stimulation gefunden werden konnte. Dementsprechend haben die relativ blinden Felder nach jeder temporalen Stimulation abgenommen, mit Ausnahme einer Zunahme nach der statischen Stimulation. Im Vergleich zur statischen Stimulation haben die relativ blinden Felder allerdings nach jeder temporalen Stimulation abgenommen. Die absoluten Felder waren nach jeder Stimulation nicht mehr vorhanden. Die Ergebnisse entsprachen denen die bei Patient LE in Experiment 1 und 3 gefunden wurden (siehe Kapitel III und IV).

Da die intakten Felder nur ganz leicht nach der statischen Stimulation, aber ganz stark nach der temporalen, zugenommen haben, kann auch aus diesem Experiment geschlossen werden, dass es nicht unbedingt „nicht-beschädigte“ Axone sein müssen, die bei Patient LE zu einer Restwahrnehmung geführt haben und dass die externe temporale Stimulation die Restwahrnehmung erhöhen konnte.

Im Allgemeinen kann geschlussfolgert werden, dass durch eine temporale Stimulation die intakten und defekten Felder der Übergangszone verändert werden können- und zwar für Patienten mit verschiedensten Läsionen und unterschiedlichem Läsionsalter. Dies steht im Gegensatz zu Horton (2005) der bezüglich VRT postuliert hat, das ein und dasselbe Trainingsprogramm für die verschiedensten Läsionen nicht möglich sei, da es keinen physiologischen Mechanismus gebe, der gleichzeitig die Verbesserungen beispielsweise nach einer monokularen Nervus opticus Erkrankung und post-chiasmatischer Läsionen erklären könne.

Eine Erklärung für die Befunde der kortikal blinde Patienten RP und FS und des nicht-kortikalen Patienten LE könnte das „dynamische“ System sein, das als allgemeiner Mechanismus fungiert, der zu einer neuronalen Plastizität führt (im Sinne einer Rekonfiguration des neuronalen Netzwerkes das der visuellen Wahrnehmung zugrunde liegt), die wiederum nach einem gezielten Training zu einer Verbesserung der defekten Felder führen könnte. Es kann also angenommen werden, dass durch die gezielte temporale Stimulation eine unzureichende, „geschädigte“ Synchronizität, die einem Wahrnehmungsdefizit zu Grunde liegt (z.B. Singer, 1999 und Vanni et al., 2001), aufheben oder zumindest teilweise wieder herstellen kann. Um dies herauszufinden, müssen weitere Untersuchungen mit verschiedensten temporalen Stimulationen und ein Training im Sinne von regelmäßiger Stimulation durchgeführt werden.

## Schlußfolgerungen: Zusammenfassung

Zusammenfassend konnte die Studie zeigen, dass die Blindsichtfähigkeit gesteigert oder erzeugt werden kann, wenn den Patienten temporal modulierte Stimuli dargeboten werden. Daraus kann geschlossen werden, dass visuelle Prozesse (im Speziellen Figur- oder Formwahrnehmungsprozesse) durch das synchrone Feuern der Neuronen beeinflusst, wenn nicht gar vermittelt werden. Eine externe temporale Stimulation (Elliott & Müller, 1998) kann dabei die geschädigte, interne Synchronizität beeinflussen und wieder zu einem Gleichgewicht der visuo-kortikalen Funktion führen. In diesem Zusammenhang kann weiter geschlossen werden, dass durch die temporale Beeinflussung „höhere“ Prozesse den geschädigten oder nicht vorhandenen Input von V1 kompensieren und diese Kompensation für die visuelle Restkapazität bzw. Blindsicht im defekten Gesichtsfeld verantwortlich ist.

Des Weiteren konnte gezeigt werden, dass temporale Stimulation zu morphologische Veränderungen im Gesichtsfeld führen kann, unabhängig vom Alter der Läsion, der Art der Läsion oder des Alters der Patienten. Dies zeigt einmal mehr, dass eine Läsion im zentralen visuellen System nicht immer zu einem kompletten und permanenten Verlust der visuellen Funktion führen muß (siehe auch Zihl & von Cramon, 1979). Wie diese Veränderungen stabilisiert werden und Patienten somit langfristig davon profitieren können, wäre eine Anregung für weitere Untersuchungen.

# Curriculum vitae

## Doerthe Seifert

Born on March 9th 1972 in Hamburg (Germany)

## Education

| | |
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| 2003 - 2006 | Ph.D. in Psychology |
| 94/95 - 2003 | Diploma in Psychology (Department of Psychology, Ludwig-Maximilians-University, Munich, Germany); 2002 Intermediate Diploma in Psychology (University of Hamburg, Germany)<br>Romance studies and educational science (University of Hamburg, Germany; Universiteit van Amsterdam, Netherlands; Universität Würzburg, Germany); 1997 Intermediate Diploma in education science (University of Hamburg, Germany) |
| 1993 - 1994 | Restoration (painting) and Gallery Apprentice (Hamburg, Germany) |
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## Professional Experience

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| 2003 – 2006 | Researcher (Department of Psychology, Ludwig-Maximilians-University, Munich, Germany) |