Eur Arch Psychiatry Clin Neurosci (1996) 246:256–260

ORIGINAL PAPER

U. Schneider · F. M. Leweke · U. Sternemann
M. M. Weber · H. M. Emrich

Visual 3D illusion: a systems-theoretical approach to psychosis

Received: 26 July 1996 / Accepted: 26 April 1996

Abstract Binocular depth inversion represents an illusion of visual perception. Such an inversion does not occur in all cases, especially when objects with a higher degree of familiarity (e.g. photographs of faces) are displayed. Cognitive factors are assumed to override the binocular disparity cues of stereopsis. We tested the hypothesis that during psychotic and similar states the human CNS is unable to correct the implausible perceptual hypothesis. Measurements of binocular depth inversion in perception of 3D objects were performed in schizophrenic patients (n = 13), in patients with alcohol withdrawal (n = 10), in sleep-deprived medical staff (n = 10) and in healthy volunteers (n = 41). The binocular depth inversion scores were highly elevated in the patient group and in the sleep-deprivated medical staff in comparison with healthy volunteers. The data demonstrate that impairment of binocular depth inversion reflects a common final pathway, characterized by an impairment of adaptive systems regulating perception.

Key words Binocular depth inversion · Schizophrenia · Alcohol withdrawal · Sleep deprivation · Systems theory

Introduction

Symptoms of schizophrenia include hallucinations, delusions, thought disorder and negative symptoms. Broadbent [1] proposed a model of information processing in perception, according to which the data-transmission system has a limited capacity for the amount of information which can be transmitted. He hypothesized the existence of a "filter", which selects the information flow from the sensory input to the "limited capacity channel (p-system)". This structure is relevant in "focused" or "selective" attention [3, 13]. These authors suggested that schizophrenic patients suffer from an information overload due to a breakdown of selective attention, in which "consciousness is flooded with an undifferentiated mass of incoming sensory data". One problem in the proposed model is that filtering does not yield a simple explanation of hallucinations, because filter functions regulate sensory inputs only and give no hint as to the mechanisms of endogenous productions which are experienced during hallucinations. It is possible that schizophrenic patients are aware not only of the externally raised sensory data, but also of their internal productions of conceptualizations and fantasies.

According to the current view, perception is not a singular process; rather, it is assumed to result from interaction between different subsystems. Two components of the sensory system have to be considered, one "bottom-up" component, and an additional "top-down" component, a conceptualization system which describes the strategies as to how the bottom-up data sets have to be interpreted. The results of such interactions between these two components are sometimes ambiguous. Alternative interpretations may be possible and thus may lead to internal conflicts. One possibility is that a decision is executed by the activity of a third component, an "adaptive processor". This assumed third component has to perform decisions in ambiguous situations. The neurobiological realization of such an adaptive control process may be performed by a set of association loops between the conceptualization system and cortical structures. This leads to an adjustment of possible contents of perception to actual contexts, as well as to memory data regarding experiences which were already acquired in the past by the system.

The complex interaction taking place during the perceptual process described above leads to the "three-component hypothesis" of the organization of the perceptual process: Firstly, the sensory input (i.e. bottom-up component); secondly, the conceptualization (i.e. top-down component); and thirdly, the adaptive component. The "adaptive processors" appear to play a role in the interactional

U. Schneider · F. M. Leweke · U. Sternemann · H. M. Emrich (✉)
Department of Clinical Psychiatry and Psychotherapy,
School of Medicine, D-30625 Hannover, Germany

M. M. Weber
Max Planck Institute of Psychiatry, D-80804 Munich, Germany

organization of the CNS. They may be functionally related to the acquisition of new "reality fictions" in the terminology of constructivism, e.g. of Watzlawick [19], and an impairment of such adaptive systems may be plausible explanation for the disintegrative and reality-impairing properties of psychotic disorders [5].

The interaction between the three above-mentioned components is assumed to be responsible for a biologically significant and senseful internal representation of the external world during perception. The question arises as to which "equilibrium" is disturbed during psychosis between these three components [4, 5].

The human visual system has several sources of information for recovering 3D shape from 2D images. Various perceptual cues for 3D shape are used by humans, such as binocular vision, intraocular rivalry, motion parallax, texture gradients, contour lines and lighting direction. Wheatstone [21] first identified a source of information used by human vision to obtain a 3D shape, the binocular disparity. It relies on the horizontal retinal disparity between the images of an object projected on the two retinas.

The understanding of different cues had led to a considerable corpus of knowledge about how individual cues signal 3D shape. More recently, the interest has turned to the interactions between different cues. The question of how different cues may actually be used in a consistent way, when the human visual system is inspecting 3D objects, in which multiple cues are available, is still an unanswered question.

In 1852 Wheatstone [22] reported that when the disparity of objects is reversed by interchanging the view of the left and right eye ("pseudoscopy"), apparent depth is also reversed. When pictures are placed in a stereoscope so that an impression of depth is given, such depth is inverted when the two pictures are reversed from left to right and vice versa.

In 1981 Yellot [24] demonstrated that stereoscopic visual experience is the result of a process in which the brain tests hypotheses about the 3D shape of objects against the evidence provided from their retinal representations.

Binocular depth inversion does not occur under all conditions with hollow 3D objects. Especially when photographs of faces are displayed, such inversion does not occur. They show either essential normal depth or lack of all depth when they are viewed pseudoscopically.

For many years it has been generally assuemd that cognitive influences counteract the perception of the improbable shapes and depth relations produced by pseudoscopy of natural objects. The resistance to reversal of depth has been attributed to familiarity with the shape of objects and the presence of monocular depth cues.

Only Van den Enden and Spekreijse [17] assumed that cognition is not a relevant factor in the resistance to depth inversion when the left- and right-eye views are interchanged. They postulate that texture disparity is the main factor in resistance to the reversal of depth. Visual illusions have already been used in investigations on psychopathology and abnormalities in schizophrenic patients. In this study only natural images were used. The most obvious uncertainty which arises from the use of synthetic images is the possibility that these images lack some of the cues exploited by human observers when inspecting natural scenes.

The current hypothesis was that the "equilibrium" between the three above-mentioned perceptual components may be disturbed during psychosis and propsychotic states, resulting in an impairment of binocular depth inversion.

Method

This hypothesis was tested on schizophrenic patients during alcohol withdrwal and on sleep-deprived medical staff using a model which has been described previously [6].

Thirteen schizophrenic patients (aged 21–52 years; 8 females and 5 males) and 20 healthy volunteers (aged 20–48 years; 13 females and 7 males) as a control group participated in the study. The control group was recruited from hospital medical staff or subjects who responded to a local newspaper advertisement. Subjects were asked about intake of psychopharmacological medication and their history of psychiatric problems, and were excluded from the study if there was a positive response. The patients had received a diagnosis of schizophrenia according to DSM-IV and ICD-10 criteria. Mean scores on the Brief Psychiatric Rating Scale (BPRS) were 39. The schizophrenic patients had consecutively admitted been to the psychiatric unit at Medical School, Hannover, and had vivid productive symptoms (auditory hallucinations, acute delusions, e.g. depersonalization and derealization experience, etc.) according to the Positive and Negative Syndrome Scale (PANSS).

In addition, 10 patients with alcohol withdrawal (aged 31–48 years; 4 females and 6 males) and 11 healthy volunteers (aged 22-35 years; 7 females and 4 males) participated in the study, completing the same experimental procedure. The healthy volunteers were without any psychopharmacological treatment and without any psychiatric history. The patients were tested with the CIWA-Ar scale [16]. This is a ten-item scale for clinical quantification of the severity of the alcohol withdrawal syndrome. Only patients with a low score (< 10), and without auditory, visual and tactile hallucinations were included in the study. The patients with a concurrent withdrawal from other drugs, e.g. benzodiazepines, or a history of psychotic disorders were excluded. When starting the investigation the patients were not receiving pharmacological treatment.

Additionally, sleep-deprived medical staff (aged 23–48 years; 2 males and 8 females) and 10 healthy volunteers (aged 23–36 years; 2 males and 8 females) took part in the study. Both groups were without any pharmacological treatment. Exclusion criteria included past or present psychiatric illness, concomitant use of drugs or alcohol, greater caffeine consumption than one cup of coffee or tea per night and naps during the night.

The medical staff were instructed to take a normal night of sleep before the study and not to sleep during the day before the period of sleep deprivation. The experiment started at 20:00 before the medical staff commenced work. The next morning at 6:30, after 1 night without sleep, a second experiment was performed. One week later a third experiment was completed.

Ten healthy volunteers served as controls, experiencing a similar experimental procedure, but without any sleep deprivation and without any work at night. They had normal sleep of approximately 9 h during the study and did not consume caffeine, alcohol or any medications.

The following technique was used: different stereoscopic slides were displayed in random order by a device with two slide-projectors using cross-oriented linearly polarized light, and glasses with corresponding filters for the patients and the healthy volunteers.

Before starting the investigation, stereopsis was tested using the TNO test for stereoscopic vision (Lameris, Utrecht) and had to amount to at least 60 s of arc in each object. Pseudoscopy was induced by exchanging the slides in the slide projectors from right to left, and vice versa. Every slide set was displayed for 30 s. As a control paradigm to exclude response bias effects, slide sets were displayed either reversed from left to right, and vice versa, or not reversed in random order. Only slides with different natural images were used (e.g. faces, houses, flowers). All subjects underwent a physical examination before starting the investigation and gave their informed consent prior to their inclusion in the study. Patients and volunteers described their visual experience during pseudoscopic projection by the following procedure: Score 1 was constituted from the data from four slides of objects exhibiting a high degree of familiarity (e.g. house, teddy mask, garden chair, human face). A description of three criteria within every slide was given which characterized binocular depth perception of special parts of the object (i.e. description of depth perception of, for example, nose, eyes, cheeks, roof, etc.). A maximal score of two points was reached on every slide if the three criteria were fulfilled within 30 s.

A similar procedure was used to constitute score 2 (i.e. brushwood, flowers), in which semantically less relevant objects with a lower degree of familiarity were visualized. In score 1 a maximum of 8 points (100%), and in score 2 a maximum of 4 points (100%), could be attained.

Results

The results concerning the schizophrenic patients are shown in Fig. 1. Score 1 (pictures with a high degree of familiarity) was highly elevated in productive patients (68.7%) in comparison with healthy volunteers (8.7%), and the difference was statistically highly significant ($P < 0.001$; Mann-Whitney test, two-tailed). In score 2 (pictures with a lower degree of familiarity) the results were analogous, but the differences were less pronounced ($P < 0.05$).

The results referring to the patients with an alcohol withdrawal are shown in Fig. 2. The average scores of the patients with alcohol withdrawal were highly elevated in comparison with healthy volunteers ($P < 0.05$; Mann-Whitney test, two-tailed). When visual information was displayed to the correct eye, there were no significant differences between the score of the patients and the controls. These results reflect the reduced binocular depth inversion of patients with alcohol withdrawal.

The results of the sleep-deprived medical staff are shown in Fig. 3. There were no significant differences between the medical staff and healthy volunteers before sleep deprivation. After the first night without sleep, the average score of the medical staff was highly elevated in comparison with other healthy volunteers ($P < 0.05$, Mann-Whitney Test, two-tailed). After resting 7 days the differences between the medical staff and healthy volunteers were diminished and no statistically significant differences between the two groups remained.

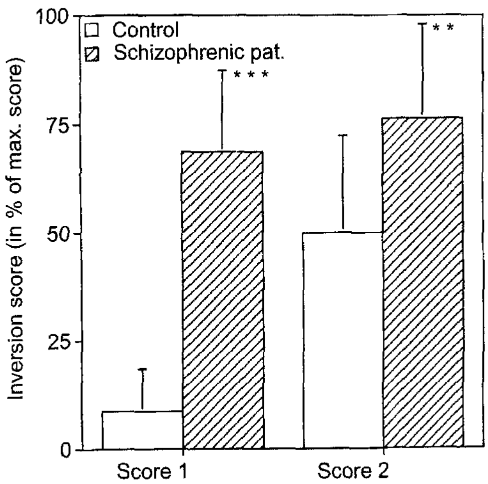

Fig. 1 Inversion score in schizophrenic patients and normal controls, presenting pictures with a high degree of familiarity (score 1) and with a lower degree of familiartiy (score 2)

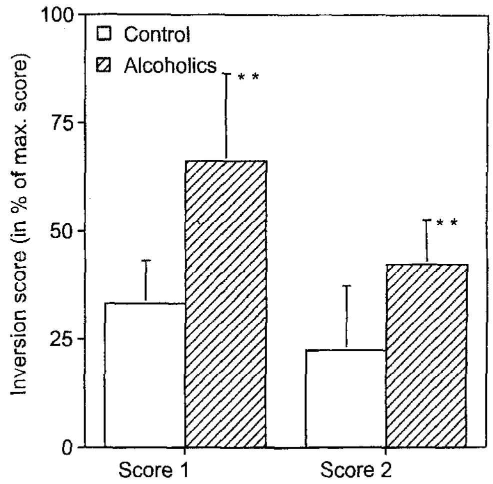

Fig. 2 Inversion score in patients with a mild alcohol withdrawal and normal controls (scores 1 and 2)

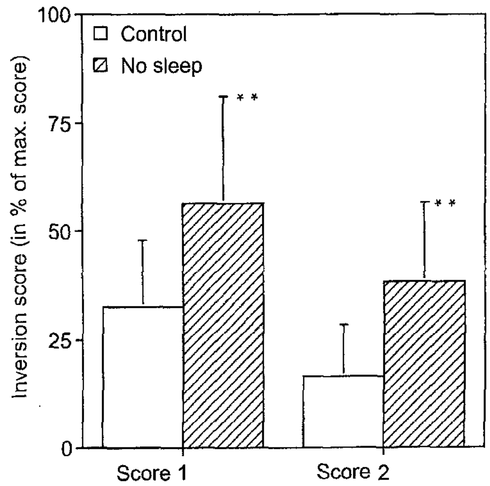

Fig. 3 Inversion score in sleep-deprived medical staff and normal controls (scores 1 and 2)

Discussion

Visual illusions have already been used in investigations into psychopathology and abnormalities of perception in schizophrenic patients. The advantage of testing binocular depth inversion is that it allows for an evaluation of the function of an adaptive „correcting" system, which is dependent in its activity on the semantic properties of the visualized objects. These inversion-inducing properties of 3D complex accustomed objects have to be further investigated using quantitative methods, and such a research program has been started [4]. The results strongly support the view that endogenous productive psychoses are due to a disorganization in the interaction between generation of perceptual hypotheses, the sensory data and their plausibility control.

Malenka et al. [12] and Frith and Done [7] found that schizophrenic patients failed to make rapid error corrections when immediate visual feedback about their responses was not available. The suggestions of Malenka [12] Frith and Done [7] and Huxley [11], are in line with our concept insofar as it is assumed that internal correcting and adaptive systems are deficient or in imbalance in relation to the generation of concepts during a psychotic status [7, 8].

Endogenous schizophrenic disorders preferentially are characterized by auditory, and only rarely by visual, hallucinations, whereas the assumed adaptive correcting system, demonstrated in our results, refers to the visual system. A possible explanation is that in productive psychosis a great number of different adaptive systems may simultaneously be impaired by the disease process.

Alcohol withdrawal as well as prolonged sleep deprivation can precipitate psychotic symptomatology [10, 20]. Also, the data from the patients with alcohol withdrawal, after sleep deprivation, and cannabis intake [6], show a remarkable impairment of binocular depth inversion.

Thus, the binocular-depth-inversion test could possibly be a relatively sensitive test of psychotogenic compounds and of the psychotropic activity of psychedelic drugs as well as of the presence of an organic psychotic state. From this viewpoint the binocular depth inversion is expected to represent not a diagnostic test of the disorder "schizophrenia", but to monitor a final pathway which is characterized by an impairment of systems regulating perception.

A possible interpretation of the system deficiency in this final pathway is an imbalance between overactive conceptualizing and relatively insufficient adaptive systems. The vulnerability of the system is assumed to be a consequence of this latent imbalance, which manifests when a challenging experience induces an increase in the activity of the conceptualizing system. The impairment of binocular depth inversion seems to reflect a common final pathway of "psychosis" and does not reflect pathogenetic features. The advantage of testing binocular depth inversion is that it allows to monitor a final pathway, which is characterized by an impairment of sensual adaptive systems regulating perception control.

Perception is not a singular process. It is assumed to result from the interaction of different subsystems. Two main components have to be taken into account, the bottom-up component and a top-down component. However, the visual system cannot be characterized generally by simple dichotomies such as bottom-up vs top down. It appears that different mechanisms are available to this system [18].

The concept of the present paper is at odds with the "filter-deficiency" model of Chapman and Chapman [3], based on Broadbent's [1] explanation of selective attention by a filtered information flow through a channel with limited capacity. Such a neurochemical "filter model" has been proposed by Carlsson [2]. According to this model dopamine-modulated cortico-thalamo-cortical feedback loops are impaired in schizophrenic patients. He assumes that the cortico-striato-thalamic loop represents a "thalamic filter" which is controlled by dopaminergic pathway, and that an increased dopaminergic tone would increase the information load on the cerebral cortex and cause arousal. Therefore, an antidopaminergic drug would increase the filter function, and thus improve selective attention in psychotic patients.

However, as already mentioned, such a model could explain productive symptoms of the perceptual system only if an additional filter defect would also relate to a control of internal conceptualizations. The model, presented herein, attributes the basic disturbance to an insufficiency of an adaptive system.

The question is: In which way may such a system be realized. The hippocampus seems to control the processing of sensory input consolidation, storage, retrieval and regulation with motivational influences into complex cortical functions during the development of an acquired behaviour [9, 15]. Hippocampal structures play an important part in generation of predictions about plausible sensory inputs from the outer world and in comparing these predictions with actual inputs. The system functions as a "comparator" [9]. Additionally, the hippocampal structures are proposed to act as a high-capacity-memory buffer.

Mumford [14] assumed that thalamocortical feedback loops are associated with conceptualizing and hippocampal structures are important concerning control of sensory-input plausibility. Investigations of patients who suffer from acute temporal-lobe lesions with such binocular depth inversion illusion experiments have just been started and seem to be supportive of our concept. Due to the small database, no definitive conclusions can be reached presently.

References

1. Broadbent D (1958) Perception and communication, Pergamon Press, New York
2. Carlsson A (1988) Speculations on the control of mental and motor functions by dopamine-modulated cortico-striato-thalamo-cortical feedback loops. M Sinai J Med

3. Chapman LJ, Chapman JP (1973) Disordered thought in schizophrenia. Meredith, New York
4. Emrich HM (1988) Zur Entwicklung einer Systemtheorie produktiver Psychosen. Nervenarzt 59:456–464
5. Emrich HM (1989) A three-component-system-hypothesis of psychosis. Impairment of binocular depth inversion as an indicator of functional dysequilibrium. Br J Psychiatry 155 (Suppl 5):37–39
6. Emrich HM, Weber MM, Wendl A, Zihl J, Meyer L von, Hanisch W (1991) Reduced binocular depth inversion as an indicator of cannabis-induced censorship impairment. Pharmacol Biochem Behav 40:689
7. Frith CD, Done DJ (1989) Experiences of alien control in schizophrenia reflect a disorder in central monitoring of action. Psychol Med 19:356–363
8. Frith CD, Done DJ (1988) Towards a neuropsychology of schizophrenia. Br J Psychiatry 153:437–443
9. Gray JA, Rawlins JNP (1986) Comparator and buffer memory: an attempt to integrate two models of hippocampal functions. In: Isaacson RL, Pribram KH (eds) The hippocampus, vol 4. Plenum Press, New York, pp 159–201
10. Heinemann LG (1966) Der mehrtägige Schlafentzug in der experimentallen Psychoseforschung: Psychopathologie und EEG. Arch Psychiatr Z. Ges Neurologie 208:177–197
11. Huxley A (1954) The doors of perception. Chatto and Windus, London
12. Malenka RC, Angel RW, Hampton B, Berger PA (1982) Impaired central error-correcting behavior in schizophrenia. Arch Gen Psychiatry 39:101–107
13. McGie A, Chapman J (1961) Disorders of attention and perception in early schizophrenia. Br J Med Psychol 34:103–117
14. Mumford D (1992) On the computational architecture of the neocortex. Biol Cybern 66:241–251
15. Olton DS (1989) Mnemonic functions of the hippocampus: single unit analyses in rats. In: Chan-Palay V, Köhler C (eds) The hippocampus: new vistas. Liss, New York, pp 411–424
16. Sullivan JT, Sykora K, Schneidermann J, Naranjo CA, Sellers EM (1989) Assessment of alcohol withdrawal: the revised clinical institute withdrawal assessment for alcohol scale. Br J Addiction 84:1353–1357
17. Van den Enden A, Spekreijse H (1989) Binocular depth reversals despite familiarity cues. Science 244:959–961
18. Wagemans J, Kolinsky R (1994) Perceptual organisation and object recognition – POOR is the acronym, rich the notion. Perception 23(4):371–382
19. Watzlawick P (1985) Wirklichkeitsanpassung oder die angepasste „Wirklichkeit“? In: Einführung in den Kontruktivismus (Schriften der Carl-Friedrich-von-Siemens-Stifung, Bd. 10) Oldenbourg, München
20. West L, Janszen HH, Lester B, Comelisoon FS (1962) The psychosis of sleep deprivation. Ann N Y Acad Sci 96:66–70
21. Wheatstone C (1838) Proc R Soc 128:371–394
22. Wheatstone C (1852) Philos Mag 4:504
23. Wolf R (1985) Binokulares Sehen, Raumverrechnung und Raumwahrnehmung. Biologie unserer Zeit 15:161–178
24. Yellott JI (1981) Binocular depth inversion. Sci Am 245:118–125