Title	The visual hallucinatory response to flickering polychromatic light.
Author(s)	Elliott, Mark
Publication Date	2004
Publication Information	Becker, C., & Elliott, M.A. (2004). The visual hallucinatory response to flickering polychromatic light. in A.M. Oliveira, M. Teixeira, G.F. Borges & M.J. Ferro. (Eds.). Fechner Day 2004. Proceedings of the Twentieth Annual Meeting of the International Society of Psychophysics. Coimbra, Portugal. The International Society for Psychophysics, (pp. 146-151).
Publisher	The International Society for Psychophysics
Link to publisher's version	http://academia.edu.documents.s3.amazonaws.com/1691783/Becker___Elliott.pdf
Item record	http://hdl.handle.net/10379/1553

THE VISUAL HALLUCINATORY RESPONSE TO
FLICKERING POLYCHROMATIC LIGHT

Cordula Becker & Mark A. Elliott
Temporal Factors and Psychophysics Lab, Department Psychologie,
Ludwig-Maximilians-Universität, Leopoldstr. 13, 80802 München, Germany
cbecker@psy.uni-muenchen.de, elliott@psy.uni-muenchen.de

Abstract

Our understanding of human visual perception generally rests on the assumption that conscious visual states represent, in some qualitative fashion, a complex interaction between spatially structured variations in the ambient optic array and our visual nervous systems. The existence of visual hallucinations in a number of pathologies (e. g. Kolmel, 1984) as well as in experimental contexts (Fechner, 1838; Benham, 1895; Herrmann & Elliott, 2001; Knoll & Kugler, 1959) questions the assumption that what we see in the environment is necessarily determined by spatial structure in the distal stimulus. Here we show that complex colour and form hallucinations are evoked by flickering light and that the type of hallucination varies with flicker frequency flicker phase and the occurrence of other flicker induced hallucinations. This evidence supports theories of consciousness that stress temporal aspects of perceptual processing.

Contemporary perspectives hold conscious experience as an emergent property arising from synchronous oscillations at widely dispersed brain areas (Tononi & Edelman, 2002). Nevertheless, the question of whether or not the mechanisms responsible for conscious content depend upon precise temporal coding remains a problem of considerable complexity. It has been shown that an hallucinatory experience of visual percepts might be brought about through electrical stimulation (Knoll & Kugler, 1959) or by means of photic driving, that is as a function of exposure to high frequency flicker (Eichmeier & Höfer, 1974; Herrmann & Elliott, 2001). A hallucinatory experience involves the perception of an external object or event in the absence of object-related information in the ambient optic array. Pure visual hallucinations are thus conscious states that appear to occur solely as a function of our visual nervous systems and with no obvious spatial reference in the visual world. If hallucinatory experience can arise solely as a function of intermittent stimulation, the possibility to describe conscious visual states exclusively in terms of variations in the temporal patterning of stimulation seemed highly promising.

General methods

A PCI technology timer card (CIO-CTR05 with CTS9513 chip capable of temporal resolutions of up to 5 kHz) was mounted in an IBM compatible PC and connected to four

LEDs (light emitting diodes) mounted in a specially constructed box. The diodes were screened from view and projected onto a uniform white screen (of 10 x 20 cm) mounted some 12 cm from the viewing aperture. Through the viewing aperture observers viewed the projection of simultaneous, square-wave light pulses of 13 cd/m^2 emitted from the diodes onto the white screen, which for a certain range of presentation frequencies (< ~38 Hz) was experienced as a Ganzfeld of spatially homogeneous flicker. For higher frequencies above the flicker fusion threshold, observers viewed apparently constant illumination in a spatially homogeneous field.

For all experiments, observers were screened for neurological and in particular neuroleptic disorders, were informed of the nature of the study and provided signed consent to participate. Additionally, the experiments were conducted under the guidelines of the American Psychological Association and the Helsinki declaration of human rights.

Experiment 1

In a series of studies we investigated reports of visual hallucinatory experiences in response to flickering light. Experiment 1 determined the type of hallucinatory experience and the range of flicker frequencies over which hallucinations were experienced.

In Experiment 1, 9 paid observers (3 male, mean age 25 years, vision normal or corrected to normal) were presented with 60 90-second trials (60 seconds of flicker followed by a 30 seconds dark period) of flickering stimulation at frequencies of integer multiples between 1 and 60 Hz (presentation order randomised, divided between two experimental sessions). Using a free report paradigm, observers were asked to verbally describe any visual colour, form and motion hallucinations experienced concurrent with the flickering stimulation.

Hallucinations were usually highly complex in nature, resembling kaleidoscopes of varying forms and colours which might undergo a number of transformations during a given period of stimulation. Examining the distribution of reports over frequency included an assessment of the reliability of reports related to each type of hallucinatory experience. As a rule of thumb, reports were considered for further analysis when at least 50% of observers offered the same report for at least one frequency. For these reports, probability densities over stimulating frequency were then estimated using a Gaussian kernel with a bandwidth based on the Silverman (Silverman, 1986) algorithm (see Figure 1a and Figure 2a), while the ranges over which the peak densities might be concluded to be significantly different from no observations were inferred using an identical algorithm applied with the SiZer method (Chaudhuri & Marron, 1998) (see Figure 1b).

The reported hallucinatory experiences were qualitatively consistent with those reported to accompany electrical, magnetic or optical stimulation (Eichmeier & Höfer, 1974). It was determined that observers reported eight, qualitatively different colour hallucinations (with SiZer midranges in Hz) (purple [12–21], blue [13-53], green [12-22], yellow [12-56], red [13-21], black [9-20], white [7-52] and grey [5-55]) and the hallucination of nine distinct, spatially structured variations (lines [8-25], waves [9-32], circles [10-36], radials [15-30], spirals [15-30], gratings [8-39], points [9-40], rectangles [9-35] and zigzag patterns [9-15]).

The tendency for hallucinatory experiences of form and colour to be non-uniformly distributed over flicker frequency indicates the existence of critical bandwidths within which mechanisms responsible for the emergence of conscious visual states may be triggered by the periodic response of mechanisms sensitive to transient contrast changes at particular frequencies. Analysis of hallucinatory reports undertaken by means of two separate loglinear analysis for colour and form hallucinations revealed a complex interaction structure (described in Table 1). The presence of interactions indicates that the occurrence of a given hallucination during a stimulation period is dependent upon the occurrence or the probability of occurrence of other hallucinations of particular types in the same stimulation period.

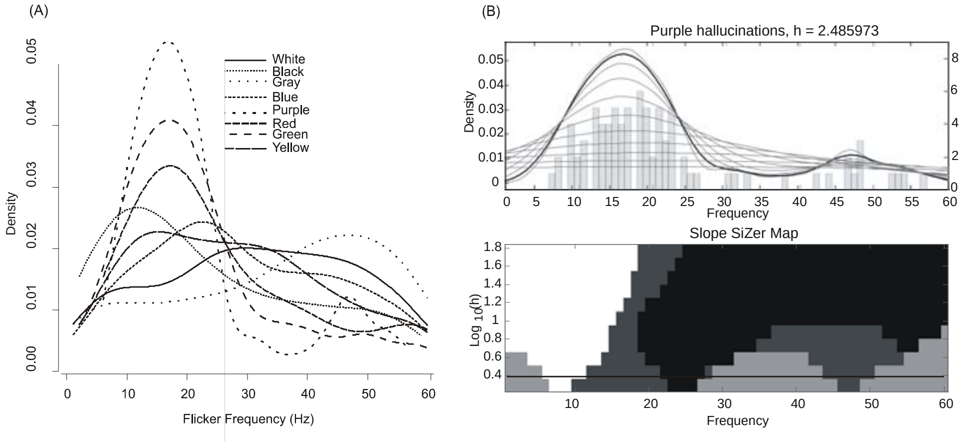

Figure 1 (a) Density estimates for colour hallucinations over flicker frequency in Experiment 1. (b) SiZer plot representing density estimates for reports of purple hallucinations. The upper panel shows the number of reports indicated in the histogram with density estimates of the raw data based on different smoothing bandwidths. The thick curve is the result of a smoothing process using a bandwidth h estimated using the Silverman (Silverman, 1986) algorithm. In the lower panel SiZer plots are shown with the horizontal black line corresponding to the h value of the above highlighted curve. White and black signals a significant increase and decrease of the density curve, respectively. Dark grey indicates a region of no significant change in density, while light grey indicates regions with too few observations to infer density. The dark gray midrange is considered a significant peak in the density estimate given the assumption that a significant peak will be flanked by a significant increase in density on one side (white) and a significant decrease (black) on the other.

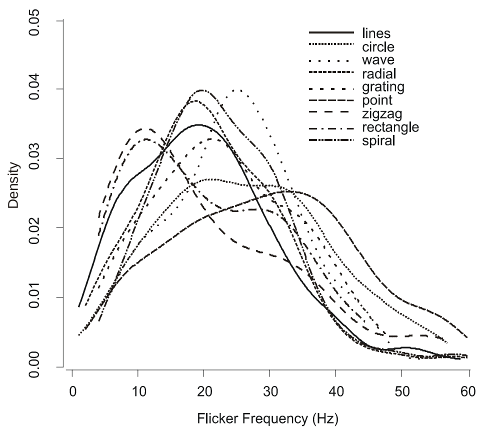

Figure 2 Density estimates for hallucinations of spatial structures over flicker frequency in Experiment 1.

Table1 Significant interactions derived in loglinear analysis calculated separately for colour and form hallucinations in Experiment 1.

Co-occurrent colour hallucinations		
white purple red green	white black	gray green
black purple green	gray blue	blue green
blue purple green	white purple	purple green
white black yellow	blue red	red green
black purple yellow	purple red	blue yellow
purple green yellow	black green	purple yellow
		green yellow
Co-occurrent form hallucinations		
circle wave grating point	circle radial square	lines radial
circle wave point zigzag	circle grating square	wave zigzag
circle wave grating	wave grating square	circle square
radial grating zigzag	circle point square	radial square
grating point zigzag	lines zigzag square	grating square
lines circle square	grating zigzag square	lines spiral
lines wave square	circle grating spiral	radial spiral
circle wave square	circle square spiral	square spiral

Experiment 2 and 3

Assuming the response in visual cortex to be periodic and to follow closely the frequency of stimulation (Herrmann & Elliott, 2001), it seems plausible to consider the activity in mechanisms related to the emergence of a given hallucinatory experience to be related to the phase of the intermittent stimulus at the time of onset of that experience. This consideration was addressed in Experiments 2 and 3, which examined the time of onset of hallucinatory experience relative to the phase of intermittent stimulation.
Each trial was of 45 seconds duration (30 seconds of flicker followed by a 15 seconds dark period). In Experiments 2 and 3 observers were asked to depress a response key as quickly as possible on first experiencing a particular hallucination. The target hallucination was announced to observers prior to trial onset in the form of a verbal instruction given via headphones. In the case that the observer did not experience the target hallucination on a given trial, the trial was allowed to time out and a zero response time was recorded. Twelve paid observers (4 male, mean age 24.4 years, vision normal or corrected to normal) were required to respond to the emergence of purple, blue, green, yellow or red in Experiment 2, while twelve paid observers (5 male, mean age 23 years, vision normal or corrected to normal) were required to respond to the emergence of lines, circles, radials, gratings, points, zigzags, rectangles and spirals in Experiment 3. The ranges of frequencies concerned were narrower than those used in Experiment 1: In Experiment 2, colour hallucinations were examined between 5 and 39 Hz and spatially structured hallucinations between 4 and 40 Hz. These ranges corresponded to the ranges over which around 75% of hallucinatory experiences were reported and were considered sufficiently broad to maintain important characteristics of the report distributions. The frequency of the presented flicker and the indicated target hallucination were varied randomly over trials, and observers were asked to respond to each type of hallucination for each level of flicker frequency.
Analyses of report frequency distributions in Experiment 2 were identical to Experiment 1. The report distributions over frequency for hallucinatory colours were similar than those revealed in Experiment 1.

Examination of the response times were confined to the SiZer midranges noted above on the assumption that hallucinations in these ranges would occur with greater than chance probability and that, consequently, the time of onset of hallucinatory experience should show the least variability. No differences were observed between response-time distributions to the presence of either colour or spatially structured hallucinations. Analysis of the relation between the times of onset of hallucinatory experience expressed in terms of phase angle relative to the frequency cycle of intermittent stimulation revealed only responses to purple to be distributed non-normally (Watson's test statistic = 0.0715). The tendency for phases to be somehow other than uniformly distributed tends to suggest that any interpretation relating the time of onset of hallucinatory experience with the phase of stimulation would not be confounded by uniformly distributed noise arising from the time taken for response preparation and execution. Closer examination revealed all other responses to be normally distributed following a von Mises distribution (i.e. the circular analogue of the normal distribution on a line (see Jammalamadaka & SenGupta, 2001)). This indicates that, irrespective to the absolute time at which a hallucination starts to be perceived, the onset time of the hallucination relates quite specifically to a particular phase of the evoking flicker. Figure 3a illustrates circular distributions related to the onset times of hallucinatory rectangles and hallucinations of the colour blue. Interestingly, the onset of different hallucinations may be distributed around different phases: Figure 3b displays the mean directions of the response distributions for form hallucinations (point 38°, zigzag 104°, circle 124°, radial 171°, rectangle 175°, line 180°, grating 319° and spiral 353°) and colour hallucinations (yellow 104°, green 133°, red 258°, purple 275° and blue 312°). It can be seen that certain hallucinations appear at close phases in the flicker cycle (i.e. lines and rectangles; blue and purple), while others are clearly separated in phase space (i.e. rectangle vs. spiral; blue vs. yellow).

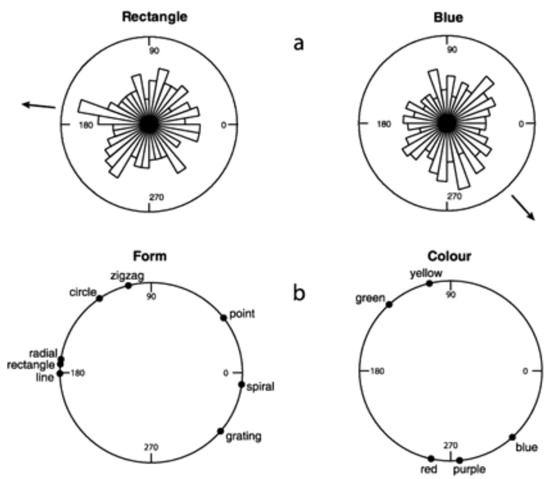

Figure 3 (a) Rose diagrams indicating the wrapped normal distribution of response times expressed in terms of phase in the flicker frequency cycle for rectangle and blue hallucinations. Arrows indicate the mean direction in phase. (b) Mean direction in phase of form and colour hallucinations. Details are given in the main body of text.

General Discussion

The hallucinations described here correspond to conscious visual experiences of forms and colours that relate solely to temporal patterning in the flow of spatially unstructured light. In fact they are experiences of visual form and colour that are entirely independent of the presence of a particular spatial structure or colour in the distal stimulus. That conscious visual states corresponding to the perception of complex visual forms and colours can arise from flickering monochromatic light is surprising enough, however flicker-evoked hallucinations also vary very precisely with frequency. They are significantly likely to occur across a narrow bandwidth approximating the EEG beta band, while their precise occurrence in time may relate to a particular phase of the photic driving frequency. Additionally, the probability of occurrence of a given hallucination is strongly influenced by the occurrence or likelihood of occurrence of other hallucinations. This offers a very strong indication that the temporal characteristic of the internal response is alone sufficient for the emergence into consciousness of various spatial structures and colours. On this conclusion, it is assumed that the systems responsible for mediating conscious experience are temporal in character and capable of representing, or carrying into consciousness a variety of visual forms. These may be coded in different frequencies or encoded in different phases of the same processing rhythm.

References

Benham, C. E. (1895). The artificial spectrum top. Nature, 2, 321.

Chaudhuri, P. & Marron, J. S. (1998). SiZer for exploration of structures in curves. Journal of the American Statistical Association, 94(447), 807-823.

Eichmeier, J., & Höfer, O. (1974). Endogene Bildmuster. München, Germany: Urban & Schwarzenberg.

Fechner, G. T. (1838). Ueber eine Scheibe zur Erzeugung subjectiver Farben. In J. C. Poggendorf (Ed.), Annalen der Physik und Chemie (pp. 227-232). Leipzig, Germany: Verlag von Johann Ambrosius Barth.

Herrmann, C.S., & Elliott, M.A. (2001). Fechner colours are induced by flickering monochromatic light. In E. Sommerfeld, R. Kompass, & T. Lachmann (Eds.). Fechner Day 2001. Proceedings of the Seventeenth Annual Meeting of the International Society of Psychophysics (pp. 427-431). Berlin: Pabst Science Publishers.

Jammalamadaka, S. R., & SenGupta, A. (2001). Topics in Circular Statistics. Singapore: World Scientific Press.

Knoll, M., & Kugler, J. (1959). Subjective light-pattern spectroscopy in the electroencephalographic frequency range. Nature, 184, 1823.

Kolmel, H. W. (1984). Coloured patterns in hemianopic fields. Brain, 107, 155-167.

Silverman, B. W. (1986). Density Estimation. London: Chapman and Hall.

Tononi, G., & Edelman, G.M. (2002). Consciousness and complexity. Science, 282, 1846-1851.