ELECTROPHYSIOLOGICAL CORRELATES OF FLICKER-INDUCED FORM HALLUCINATIONS

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Abstract

Form hallucinations can be reliably induced using temporally modulated light within a specific frequency range (15-30Hz). The neural substrates of such states have yet to be established with certainty. Brain activity of 5 'high responders' was recorded as they completed a visual report paradigm in flickering Ganzfeld (FGF) conditions. Illusory geometric forms were induced via stimulation of the Ganzfeld with rapid and intermittent square-wave light pulses of 3,000 cd/m^2 at *15-30Hz. On experiencing a specified target form (point, rectangle, spiral or circle) a left index button press was made to terminate the flicker presentation. A synchronization of activity in the theta (3.5-7Hz) and gamma (30-70Hz) frequency bands reflective of top-down and bottom-up processing respectively may enable the apperception of geometric form.*

Purkinje (1819) described the apperception of colour and form induced by vigorous hand movements across closed eyes in the face of direct and bright sunlight. Illusory phenomena of this nature are referred to as Purkinje patterns (Ffytche, 2008). Purkinje patterns can be evoked in an experimental context by stimulating the Ganzfeld with temporally modulated light within a specific frequency range (Becker, Gramann, Müller & Elliott, 2009; Becker & Elliott, 2006). While the electrophysiological (EEG) correlates relevant to the apperception of colour have been determined (Becker, Gramann, Müller & Elliott, 2009) those pertaining to the subjective experience of geometric form have yet to be established with certainty (Shevelev, Kamenkovich & Sharaev, 1996; Shevelev, Kamenkovich, Bark, Verkhlutov, Sharaev & Mikhailova, 2000; Herrmann, 2001).

Alpha oscillatory activity (8-12Hz) may in part contribute to form apperception given that periodic photo stimulation (PPS) is most effective and prompt in the generation of pseudo-hallucinatory shapes when delivered at this frequency range (Shevelev et al., 1996; Shevelev et al., 2000). Equally, an oscillating steady state visual evoked potential's successive excitation and inhibition of the retinotopic regions of the visual cortex may induce illusory colours and shapes (Hermann, 2001). As the current work is the first of its kind to employ an independent component analysis (ICA) blind source separation to assess the relative contributions of the EEG frequency bands to form apperception, no prior assumptions will be made of their functional importance.

While a little is known of the neural substrates relevant to form apperception in FGF conditions, nothing is known of the psychological factors or the elements of personality that modulate responsiveness to such perceptual deprivation. The unpublished data of Pütz, Braeunig & Wackermann (2006) (as cited in Wackermann, Pütz & Allefeld, 2008) hints that variation in personality structure may in part account for the inter-individual differences existing in responsiveness to multi-modal Ganzfeld (MMGF) stimulation. Personality structure as a modulator of responsiveness to FGF conditions will be considered.

Method

Fifteen healthy volunteers with a mean age of 21.7 years (12 female) participated in this study following the acquisition of written informed consent. All had normal or corrected to normal vision and reported no prior history of a neurological, neuroleptic or psychiatric disorder. In establishing if personality as a variable modulates responsiveness to FGF conditions each participant completed a NEO-FFI Personality Inventory (Costa & McCrae, 1992) prior to 20 minutes in FGF conditions. Following this screening, only those construed to be 'high responders' (operationally defined as any individual who hallucinated on more than one half of trials) were asked to participate in phase two (EEG experiment) of the study. The brain activity of five such 'high responders' was recorded as they completed a visual report paradigm while subject to FGF conditions.

A homogenous visual field was created by applying anatomically shaped halves of ping pong balls directly to the subject's eye orbits. This Ganzfeld was subsequently illuminated with rapid and intermittent square-wave light pulses of 3000 cd/m^2 emitted simultaneously from four white light-emitting diodes (LEDs) and at the 16 frequencies between 15-30Hz known to be effective in the induction of subjective form (Becker & Elliott 2006). Each trial consisted of a 30 second epoch of flickering stimulation during which observers were asked to make a button press as quickly as possible on experiencing a specified target subjective form (point, rectangle, spiral or circle).

An Electroencephalogram was acquired from 30 Ag/AgCl electrodes mounted according to the international 10-20 system of electrode placement. Data was sampled at 250Hz and analogue-filtered via a 0.15 high-pass filter and a 100Hz low-pass filter. Additionally, a notch filter of 50Hz was applied. An Independent Component Analysis (ICA) was employed to analyze the EEG data. The acquired ICA values were exported to Matlab where hierarchical cluster analyses (HCAs) and Fast Fourier Transformations (FFTs) with a Hanning window of 10% and a frequency resolution of 0.5Hz were performed on the averaged component time series across all subjects.

Results

A HCA of mean ICA values was conducted for each of the four conditions: points, rectangles, spirals and circles. This analysis produced a topographic distribution of the mean and standard deviation of EEG power variance across subjects in the interval 2000ms in advance to 100ms following the apperception of form. The cortical regions registering the lowest subject variability in the standard deviation of EEG power are considered the most relevant to form pseudo-hallucinations.

The HCA of the mean ICA values for the condition 'points' revealed a cluster containing all five experimental participants with a cophenetic correlation coefficient of 0.86. Brain activity in the left temporal-parietal, parieto-occipital and fronto-central regions of the scalp appeared to facilitate the apperception of points (see Figure 1).

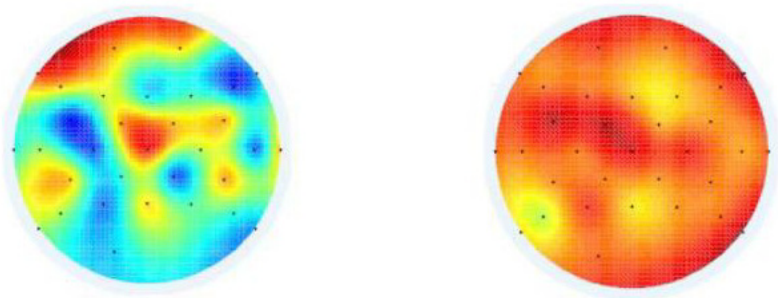

Figure 1. Points Condition– Head plots demonstrating the mean (left) and standard deviation (right) of EEG power variance across subjects in the interval 2000ms in advance to 100ms following the apperception of a point.

No meaningful results were derived from the HCA of data for the condition ‘rectangles’. In this case clusters were either of very small membership in that they were composed of less than five components or included a substantial proportion of components. Thus, there was little possibility to subdivide this data in a meaningful manner. Accordingly, no FFT was conducted for the condition rectangles.

The pattern of cortical activity generated in the apperception of spirals and circles was similar to that observed in the apperception of points. The HCA of mean ICA values for the conditions ‘spirals’ and ‘circles’ revealed clusters containing four of five experimental participants with cophenetic correlation coefficients of 0.72 and 0.6 respectively. As was the case in the apperception of points brain activity in the left temporal-parietal and the right fronto-central regions of the scalp appeared to subserve the experience of both illusory spirals and circles. The left temporal-parietal and right fronto-central regions of the brain are relevant to the apperception of illusory geometric forms (points, spirals, circles). While, parieto-occipital activation it seems is exclusive to the experience of illusory points.

An analysis of the EEG spectral power calculated via Fast Fourier Transformations indicated that synchronization in the theta (3.5-7Hz) and lower gamma (30-50Hz) frequency bands accompanied the apperception of points and circles. The perception of an illusory spiral was accompanied only by synchronization in the theta frequency band (see Figure 2).

The personality profile of an individual likely to be responsive to FGF conditions has yet to be established. An independent T-Test was conducted to evaluate if those highly susceptible to form pseudo-hallucinations in FGF conditions differed significantly in personality as measured by the NEO-FFI (Costa & McCrae, 1992) from those less responsive to this form of perceptual deprivation. High and low responders differed significantly in personality only along the dimension Neuroticism (N) (t (12) = 3.13, p =. 009), where high responders recorded a significantly higher N score (M = 26.71, SD = 5.47) than low responders (M = 18.86, SD = 3.76). Given that low Conscientiousness (C) is conducive to pseudo-hallucinatory experiences in MMGF conditions (Wackermann et al., 2008) one may have assumed this trait would be equally relevant to those induced in FGF. This is not the case. Those highly responsive to FGF stimulation were not low in C, while those highly responsive to MMGF stimulation were not reported to be high in N (Wackermann et al., 2008).

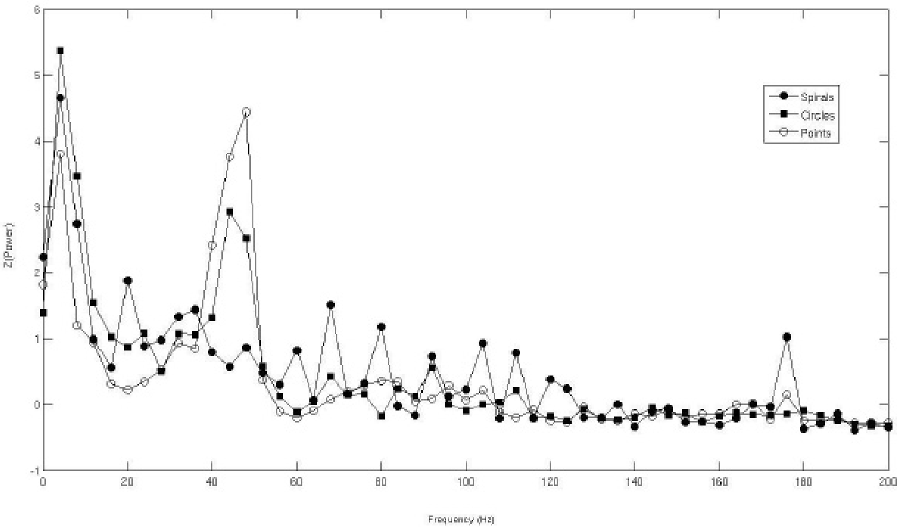

Figure 2. Fast Fourier transformation of combined ICA components derived from an interval 2000ms in advance to 100ms following the apperception of a spiral, circle and point (see text). Data are normalized by means of z transform and showpower increases in the theta (3.5-7Hz) frequency band accompanying apperception of points, spirals and circles. In addition to this a power increase in the lower gamma (30-50Hz) frequency band accompanies apperception of circles and points. Expressed in terms of in transformed power, the power associated with points at ~50Hz is around 10 x that of circles at the same maximum.

Discussion and Conclusions

The current work aimed to demarcate the electrophysiological correlates of geometric form apperception. The topographic renditions of EEG power variance across subjects demonstrated that temporal-parietal activation is fundamental to the experience of illusory stimuli. This is unsurprising given this region of the brain is host to both the dorsal and ventral streams (Gazzaniga, Ivry & Mangun, 2009) and has a well documented role in object perception. The physiological mechanisms involved in object perception may also be involved in object apperception. Processing in the ventral stream was required to enable successful completion of the experimental task as participants had to decipher whether the form/forms observed were analogous to the specified target shape. While, processing in the dorsal stream was required to determine the spatial relations of the illusory shapes. Such activation is plausible as most participants reported the continuous movement and transformation of forms within the pseudo-hallucinatory experience.

Retinal ganglion cells may serve as a source for point apperception. Such neurons possess center-surround receptive fields highly responsive to spots of light equal to the size of their excitatory regions (Goldstein, 2007). Spots of light can be equated with the phosphenes apperceived in FGF conditions. The perception of more complex illusory forms (spirals, circles) requires cortical neurons specialized to contend with orientation, movement and size (Goldstein, 2007). The basic information acquired from these cells is projected to the higher visual areas where it is integrated to produce a coherent representation of form (Gazzaniga et al., 2009). Successive elaboration and formatting of this stimulus representation may culminate such that it matches or doesn't match a representation held in memory (Gazzaniga et al., 2007). A distinct pattern of activity in the EEG frequency bands may enable the perception of illusory form.

As this was the first time an ICA was employed to assess the relative contributions of the EEG frequency bands to form apperception, no prior assumptions were made of their functional importance. It was summated that a synchronization of activity in the theta (3.5-7Hz) and lower gamma (30-50Hz) frequency bands accompanied the experience of illusory points and circles. The perception of an illusory spiral was accompanied only by synchronization in the theta frequency band. The attenuation observed in the gamma frequency band is consistent with its established functional role. Synchronization at 40Hz provides the necessary spatial and temporal links to bind together the processing in different brain areas involved in the formation of a coherent percept (Tallon-Baudry & Bertrand, 1999). If synchronized gamma activity is reflective of a binding mechanism an increase of power should be observed on creation of a coherent form percept. Such attenuation is observed on point apperception and to a lesser extent on the perception of illusory circles. The degree of synchrony evoked may be contingent on the complexity of the target shape to be apperceived. Where the target illusory form is simple the percept generated in FGF conditions is more likely to be a coherent representation of this specified shape.

Oscillations may have numerous functions and serve as universal operators of brain activity (Başar, Başar-Eroglu, Karakas, Schürmann, 2001). This is especially relevant to gamma oscillations. Enhanced gamma synchronization may reflect the construction of an object representation via bottom-up or top-down processing (Tallon-Baudry & Bertrand, 1999). In form apperception, the power increase at 40Hz is likely to reflect the spatial binding of an object's elementary features into a coherent representation of geometric shape. A similar enhancement at 30-60Hz was observed in the bottom-up construction of coherent representations of real and illusory (Kanizsa) triangles (Tallon-Baudry, Bertrand, Delpeuch & Pernier, 1997). As gamma activity is thought to be functionally related to the phase of theta (3.5-7 Hz) oscillations these findings will in part be discussed with those in the theta frequency band.

Attenuation in theta subserved all form apperception. Such synchronization may reflect the executive functions of working memory in the retention of visual information pertaining to form composition (Sauseng, Klimesch, Gruber & Birbaumer, 2008). Participants held a template of the target shape in mind to decide if the object generated in the FGF was reflective of said form. Replication of the current results is required before theta can be ascribed a functional role in form apperception.

Conscientiousness modulates responsiveness to MMGF (Wackermann et al., 2008) but, not FGF conditions. Those highly and lowly responsive to PPS differed only in Neuroticism, with those susceptible to form pseudo-hallucinations recording a significantly higher score. This indicates that an impulsive, self conscious and emotionally volatile disposition predisposed to the experience of acute stress, anxiety and depression (Costa & McCrae, 1992) is conducive to the perception of illusory forms in FGF conditions. Interestingly, a link between such neurotic tendencies and general hallucinatory experiences (auditory and visual) has already been established in a young non-clinical sample (Laroi, DeFruyt, van Os, Aleman & Van der Linden, 2005). The personality correlates relevant to photically driven form hallucinations can be equated with those of spontaneous hallucinations.

Synchronization in the theta and lower gamma frequency bands may provide the necessary neural setting to facilitate geometric form apperception in FGF conditions. While, the extent to which one apperceives may be contingent on the extent to which one is neurotic.

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