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Theta response in schizophrenia is indifferent to perceptual illusion

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HIGHLIGHTS

- Multistable perception allows examining the patient's perceptual deficits while the stimulus remains unchanged.
- This EEG study complements behavioural studies indicating that top-down driven organising principles of perception in schizophrenia is weak.
- The altered oscillatory theta response reflects impairments in the spatio-temporal integration of the neural information transfer in schizophrenia.

ABSTRACT

Objective: Patients with schizophrenia are impaired in maintaining coherent perceptual experiences. This is reflected in the oscillatory theta response and can be investigated by visual illusions. Ambiguous stimuli elicit illusory perceptual switches while the stimulus remains unchanged.
Methods: Theta responses elicited by an *ambiguous* and *unambiguous control* stimulus were measured using the EEG during time periods of perceptual *switching* and perceptual stability (*non-switching*).
Results: For the *ambiguous* task, theta activity increased during perceptual switching in healthy controls only. For the *unambiguous* task, the switching-related increase of theta activity was larger in controls than in patients. This reduced modulation of the theta response seems not to be related to a general decrease of theta activity in patients.
Conclusions: These findings may be related to disturbances in the spatio-temporal integration of neural activity in patients. Reporting ambiguous and unambiguous perceptual switches seems to be more demanding for patients with schizophrenia than healthy controls.
Significance: This is one of the first studies on the neurophysiologic correlates of illusory perception in schizophrenia. Focussing on the relation between different brain states (such as switching and non-switching) might integrate different findings about altered theta oscillations in schizophrenia.

1. Introduction

Patients with schizophrenia are known to have problems in integrating sensory information into coherent perceptual experiences. Core symptoms of the illness, such as hallucinations, delusions and thought disorder, might be related to this impairment (Haesebaert et al., 2013; Hugdahl, 2009; Silverstein and Keane, 2011).

1.1. Top-down processes in schizophrenia investigated by visual illusions

Object perception is driven by sensory information (bottom-up) as well expectations and prior experiences (top-down, Gregory, 1997; Güntekin and Basar, 2014; Long and Toppino, 2004). The

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importance and power of top-down processes in shaping coherent perception is revealed by visual illusions (Basar-Eroglu et al., 1993; Sterzer et al., 2009). Visual illusions arise by systematic discrepancies between a stimulus and the percept due to neural processes transforming sensory information into a perceptual experience (Gregory, 1997). Patients with schizophrenia seem to be less prone to visual illusions (for a review see Notredame et al., 2014). From distance, healthy persons perceive a hollow mask as a proper face (Gregory, 1997) while patients with schizophrenia perceive the physically correct inverted face (Dima et al., 2009, 2010). Their perception seems to be driven more strongly by the sensory information (i.e., depth cues) than by top-down driven organising principles (i.e., the implausibility of a person with an inward turned nose; Dima et al., 2009, 2010).

Ambiguous stimuli elicit a special case of visual illusions. The sensory information of an ambiguous figure is inconclusive regarding the generation of coherent perception, because more than one meaningful solution is similarly probable to account for the current percept. During continuous observation, perception switches between all possible perceptual alternatives although the physical properties remain unchanged (Long and Toppino, 2004, see Fig. 1 for some examples).

The individual speed of perceptual switching (the reversal rate) is variable (Strüber et al., 2000, 2001). It remains unclear whether the spontaneous reversal rate in schizophrenia differs from healthy persons. In the few studies available the findings range from acceleration to slowing of perceptual switching (Calvert et al., 1988; Eysenck, 1952; Keil et al., 1998; Philip, 1953; Tschacher et al., 2008).

More consistent are reports about the lack of top-down control on the current percept of an ambiguous figure. The Schröder staircase has a semantic and, therefore, top-down processed bias, because perceiving the staircase from above is more realistic than perceiving it from below (see Strüber and Stadler, 1999 and Fig. 1 for ambiguous figures with different semantic biases). Patients with schizophrenia perceive the more realistic perspective of the Schröder staircase for a shorter amount of time than healthy persons (Calvert et al., 1988; Keil et al., 1998). These studies indicate that semantic properties of an ambiguous stimulus have lower impact on the perception of patients than of healthy persons. The efficiency in maintaining a desired perceptual alternative or initiating a perceptual switch by voluntary control is also diminished (Eysenck, 1952; McBain et al., 2011). Thus, behavioural studies indicate that the influence of top-down processes on the perception of ambiguous figures is diminished in schizophrenia. This is in accordance with the broader scope of the patient's deficiencies in using contextual information during object perception (Silverstein and Keane, 2011) and implies that in schizophrenia top-down driven organising principles of perception are weak (John and Hemsley, 1992; Silverstein and Keane, 2011; Tsunoda et al., 2012).

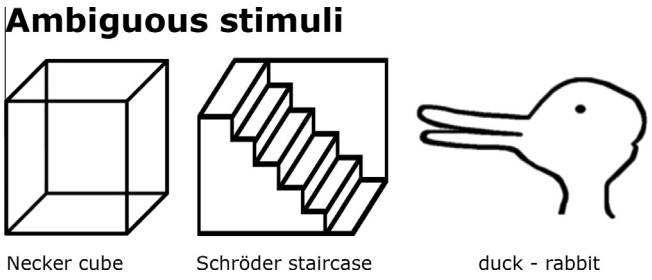

Fig. 1. Ambiguous stimuli. The figure depicts three ambiguous stimuli. Under continuous viewing condition, these stimuli induce perceptual switches even though the stimulus does not change. The Necker cube (left) can be perceived either pointing down to the left or up to the right. The perceptual switch can be described as a switch in the perspective the cube is looked at. The Schröder staircase (middle) can be perceived either from below or from above. The perceptual switch can be described again as a switch in the perspective. Please note that in everyday's experience it is more likely to perceive a staircase from above (while walking on it). This makes perceiving the staircase as from above more likely. The duck-rabbit figure can be either perceived as a duck looking to the left or a rabbit looking to the right (with the long ears pointing to the left). The perceptual switch of the duck-rabbit figure requires reconstructing the semantic meaning of the percept (see Strüber and Stadler, 1999 for more information).

To the best of our knowledge, this and our recent study (Basar-Eroglu et al., 2015) are the first that have investigated the neural processes underlying the perception of ambiguous figures in schizophrenia. This approach allows the investigation of top-down driven organising principles of visual perception in schizophrenia as they become apparent without changes of the external surrounding.

1.2. Top-down processes investigated by theta oscillations

Event-related theta oscillations (approx 4–7 Hz) have a frontal maximum (Basar-Eroglu and Demiralp, 2001) and play an important role for top-down regulated processes, such as focussed attention (Basar-Eroglu and Demiralp, 2001; Cahn et al., 2013; Polich, 2007), control mechanisms in working memory (Sauseng et al., 2010) or executive functions (Huster et al., 2013; Schmiedt-Fehr and Basar-Eroglu, 2011; Schmiedt-Fehr et al., 2011; Yordanova et al., 2004). Fronto-posterior phase-coupling of theta activity seems to be specifically important for top-down modulations of early visual areas during perceptual grouping (Volberg et al., 2013). We have recently shown that theta activity elicited by ambiguous figures is more pronounced at anterior in comparison to posterior sites than theta activity elicited by unambiguous figures. This may be indicative for an increased involvement of top-down processes during the perception of ambiguous figures (Mathes et al., 2014). Theta oscillations are further known to increase during perceptual switches elicited by both, ambiguous and unambiguous figures (Ehm et al., 2011; Nakatani and van Leeuwen, 2005). Thus, theta oscillations qualify as a neural marker to investigate possible impairments in top-down driven organising principles of visual perception in patients with schizophrenia.

1.3. Theta oscillations in schizophrenia

Theta oscillations in schizophrenia are still not well understood. The highest consensus is that slow wave activity, including theta, in patients is enhanced during rest (Boutros et al., 2008). Task-related theta activity of patients may be reduced (Bates et al., 2009; Doege et al., 2010a,b; Haenschel et al., 2009; Kaser et al., 2013; Ramos-Loyo et al., 2009; Schmiedt et al., 2005) or enhanced (Fehr et al., 2003; Hong et al., 2012a,b; Missonnier et al., 2012). Reduced theta activity may be restricted to those recording sites that are involved in task processing in healthy persons, while other recording sites rather show increased activation (Basar-Eroglu et al., 2008). The reduction of theta activity may not necessarily be a result of lower amplitudes, rather of a reduced consistency in timing the brain response with respect to a cognitive event (Basar-Eroglu et al., 2009). Results like this indicate abnormal temporal integration and interregional connectivity of brain networks as a core disturbance in schizophrenia (for reviews see Basar, 2013; Basar and Güntekin, 2013; Ford et al., 2007; Friston and Frith, 1995; Uhlhaas, 2013). These disturbances might affect the entire perception–action cycle (Fuster, 2006).

Thus, high theta oscillations during rest might be already indicative of a change in the spatial and temporal integration of neural activity in patients, possibly indicating that keeping the perceptual experience stable and coherent is a great effort for patients already in the absence of specific cognitive demands. Changes in the amplitude (irrespective of an expected increase or decrease),