Psychiatry Research 245 (2016) 58–65

Contents lists available at ScienceDirect

Psychiatry Research

journal homepage: www.elsevier.com/locate/psychres

Reduced susceptibility to the sound-induced flash fusion illusion in schizophrenia

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ARTICLE INFO

Article history:
Received 18 January 2016
Received in revised form
12 July 2016
Accepted 5 August 2016
Available online 6 August 2016

Key words:
Schizophrenia
Multisensory integration
Fission illusion
Fusion illusion

ABSTRACT

Schizophrenia is characterised by the presence of abnormal complex sensory perceptual experiences. Such experiences could arise as a consequence of dysfunctional multisensory integration. We used the sound-induced flash illusion paradigm, which probes audiovisual integration using elementary visual and auditory cues, in a sample of individuals with schizophrenia (n=40) and matched controls (n=22). Signal detection theory analyses were performed to characterise patients' and controls' sensitivity in distinguishing 1 and 2 flashes under varying auditory conditions. Both groups experienced significant fission illusions (whereby one visual flash, accompanied by two auditory beeps, is misperceived as two flashes) and fusion illusions (whereby two flashes, accompanied by one beep, are perceived as one flash). Patients showed significantly lower fusion illusion rates compared to HC, while the fission illusion occurred similarly frequently in both groups. However, using an SDT approach, we compared illusion conditions with unimodal visual conditions, and found that illusory visual perception was overall more strongly influenced by auditory input in HC compared to patients for *both* illusions. This suggests that multisensory integration may be impaired on a low perceptual level in SZ.

1. Introduction

The richness of human experience is based on the integration of different sensory stimuli. This integration is largely implicit and serves to facilitate perception and understanding in a complex sensory environment. Schizophrenia (SZ) is characterised by a disintegration of common multimodal experiences (Postmes et al., 2014) and has been conceptualised as a disorder of the normal connectivity and integration within the brain (Friston and Frith, 1995; Roiser et al., 2013; Stephan et al., 2009; White et al., 2010). The research on perceptual processing of low-level stimuli in SZ and other non-affective psychotic disorders has naturally focussed on single sensory systems, identifying subtle dysfunctions in visual, auditory and sensorimotor processing (Butler and Javitt, 2005; Javitt and Freedman, 2015; Näätänen and Kähkönen, 2009; Shergill et al., 2014), with a relative neglect of the integration of these elementary processes into the multimodal context in which the sensory experiences in psychosis often arise. Such multimodal experiences make it probable that symptoms such as hallucinations and delusions are not primarily a function of the failure within a single sensory system, but rather of an inappropriate interaction between different sensory modalities. This suggests that an understanding of multisensory integration (MSI) in non-affective psychosis may contribute to a better understanding of the clinical symptoms. In using low-level stimuli, perceptual deficits can be disentangled more readily from higher level dysfunctions, e.g. involving social cognition or learning processes.

MSI can also give rise to illusory phenomena in healthy perception. Multisensory illusions are characterised by a binding of information from different modalities in order to create a coherent unified percept, which is typically inconsistent with the true sensory input. For example, in the Ventriloquist illusion, an auditory stimulus is misattributed to the wrong source if that source provides temporally contingent visual information (Howard and Templeton, 1966). Similarly in the McGurk illusion, incongruent visual and auditory phonetic information is fused into the percept of an alternative, illusory phoneme (McGurk and MacDonald, 1976). Importantly, while non-veridical in nature, these illusions can be seen as optimal percepts given the ambiguous sensory input and learned expectations about multimodal stimuli (Alais and Burr, 2004; Körding et al., 2007). They therefore constitute markers for intact multimodal processing as seen in healthy individuals, while offering a framework in which to investigate aberrant sensory fusion in psychosis (White et al., 2014).

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http://dx.doi.org/10.1016/j.psychres.2016.08.016

Outside of the illusion literature, a dysfunction of multisensory integration in SZ has been shown in the form of reduced facilitation of speech processing by visual articulatory motion (Ross et al., 2007), and on a more elementary level with reduced reaction time facilitation in response to bimodal detection targets as compared to unimodal targets (Williams et al., 2010). Emotional voice information has further been shown to exert a reduced influence on a visual emotion categorization task in SZ (de Gelder et al., 2005). Recently, Zvyagintsev et al. (2013) demonstrated that patients with SZ show an interference effect of auditory information on a visual discrimination task both in an emotional and basic perceptual paradigm, whereas controls did not show this effect on the basic perceptual level. It is interesting to note that in the interference paradigm, an increased multimodal interaction, or "leakage" between modalities, is observed in patients compared to controls when using low-level audiovisual stimuli. Importantly, this is an attentional effect which influences the response rather than perception. In contrast, illusion paradigms predict a *reduction* in multisensory interactions in patients. In these paradigms, perception itself is altered by multimodal information, but when MSI breaks down, perception remains veridical, albeit non-optimal. Accordingly, within the multisensory illusion paradigm, patients with SZ have been shown to exhibit reduced susceptibility to the McGurk effect (de Gelder et al., 2003; White et al., 2014). However, research on susceptibility to multimodal illusions in SZ is sparse and typically makes use of high-level social or emotional stimuli. There is therefore little evidence on MSI in SZ from illusion paradigms using low-level stimulus integration.

In the current study, we used the sound-induced flash illusion (Shams et al., 2000) to examine auditory-visual integration on a very basic perceptual level in non-affective psychosis. Our sample consisted largely of patients with a diagnosis of SZ, but also included a small number of patients with schizoaffective disorder. These subgroups did not differ in terms of their symptoms, thus we shall henceforth refer to SZ as a whole for simplicity. In the sound-induced flash illusion paradigm, different numbers of brief flashes and beeps are presented contemporaneously. The classic illusion occurs when one flash accompanied by two beeps is erroneously perceived as two flashes (*fission* illusion). Conversely, two flashes are often perceived as one when they are accompanied by a single beep (*fusion* illusion; Andersen et al., 2004). Crucially, this task avoids potential confounds due to biological motion, phonetics, or social aspects often present in audiovisual paradigms (de Gelder et al., 2003, 2005; Ross et al., 2007; White et al., 2014). Previous research has shown that modulation of visual cortex activity in early stages of sensory processing is at least partially involved in eliciting the sound-induced flash illusion (Shams et al., 2005), suggesting that low level sensory processes play an important role for this illusion. It has been suggested that auditory input modulates visual cortical activation via direct pathways, resulting in the perception of an illusion. This paradigm is therefore useful in order to examine whether auditory input modulates early visual cortical processing to the same degree in SZ as it does in healthy perception.

We implemented analyses from Signal Detection Theory (SDT) in order to disentangle perceptual sensitivity from more general perceptual biases in characterising the sound-induced flash illusions. The choice of SDT measure was made in order to remain consistent with existing literature on the sound-induced flash illusion. However, there has been recent criticism of the use of SDT measures in this context (Witt et al., 2015); specifically, it has been pointed out that the criterion measure (also known as response bias) is frequently inaccurately interpreted as an internal decision criterion. We therefore emphasize that the criterion measure as used in the current study does not necessarily reflect a decisional response rule, but may indeed reflect a perceptual process. Consequently, when we use the term "tendency", we do not exclude the possibility that this may be perceptually driven – indeed we believe this to be more likely than an internal decision criterion.

Based on previous research showing that patients with SZ show reduced susceptibility to the McGurk effect (White et al., 2014) and reduced MSI (de Gelder et al., 2003; Williams et al., 2010), we hypothesised that patients would exhibit attenuated fission and fusion illusions relative to HC in our study. The sensitivity index d' was used to indicate whether illusions were due to attenuated sensitivity which was specific to illusion trials, and the criterion measure $\ln(\beta)$ was used to indicate whether auditory information created a general (likely perceptual) bias which was unspecific to the illusion trials.

2. Material and methods

2.1. Participants

Forty individuals diagnosed with a diagnosis of non-affective psychosis according to ICD-10 and 22 HC matched for age, sex, handedness, and socioeconomic background participated. Thirty-six patients had a diagnosis of schizophrenia and 4 patients had a diagnosis of schizoaffective disorder. Patients diagnosed with schizoaffective disorder did not differ from patients diagnosed with schizophrenia in terms of symptoms, and exclusion of these patients from analysis did not alter the statistical results of this study. Intelligence quotient (IQ) was measured with the two-item Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). Thirty-eight patients were taking prescribed anti-psychotic medication at the time of the study and two patients were stable off their medication for over six weeks. Chlorpromazine (CPZ) equivalent doses of medications were calculated using conversion tables (Bazire, 2005; Woods, 2003). Demographic characteristics are presented in Table 1. Exclusion criteria for all subjects were a history of neurological illness, current major physical illness, and drug dependency over the last six months. Exclusion criteria for HC were a history of psychiatric illness and a first-degree relative currently or previously suffering from a psychotic illness. All subjects had normal hearing and normal or corrected-to-normal vision. Ethical approval was provided by Central London Research and Ethics Committee. All participants provided informed written consent and were compensated for their time and travel.

2.2. Stimuli

The task was conducted as part of a larger magnetic resonance imaging (MRI) study. The fMRI data is not presented here, as it captures a different set of processes involved in this task. Visual stimuli were presented on a screen viewed via a head-mounted mirror (refresh rate 60 Hz). Each flash (F) was a white disk (diameter:1.6°; duration:16.66 ms; eccentricity:4° right off-centre) presented against a black background. Beeps (B) were presented via headphones at a volume permitting dissociation of the tone from background noise (frequency: 480 Hz; duration 16 ms). 0, 1 or 2 flashes were presented alongside 0, 1 or 2 beeps, resulting in nine possible stimulus combinations (trial types). Each trial type was presented 24 times in a randomized order, resulting in 216 trials. On congruent trials (F1B1 and F2B2), flashes and beeps had identical onsets. On incongruent trials (F1B2 and F2B1), the single stimulus in one modality was presented symmetrically in between the first and second onset of the stimuli in the other modality. The inter-stimulus-interval (ISI) between two stimuli of the same modality was determined on a single-subject level based on unimodal visual performance.