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Late, not early, stages of Kanizsa shape perception are compromised in schizophrenia

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ABSTRACT

Background: Schizophrenia is a devastating psychiatric disorder characterized by symptoms including delusions, hallucinations, and disorganized thought. Kanizsa shape perception is a basic visual process that builds illusory contour and shape representations from spatially segregated edges. Recent studies have shown that schizophrenia patients exhibit abnormal electrophysiological signatures during Kanizsa shape perception tasks, but it remains unclear how these abnormalities are manifested behaviorally and whether they arise from early or late levels in visual processing.
Method: To address this issue, we had healthy controls and schizophrenia patients discriminate quartets of sectored circles that either formed or did not form illusory shapes (illusory and fragmented conditions, respectively). Half of the trials in each condition incorporated distractor lines, which are known to disrupt illusory contour formation and thereby worsen illusory shape discrimination.
Results: Relative to their respective fragmented conditions, patients performed worse than controls in the illusory discrimination. Conceptually disorganized patients—characterized by their incoherent manner of speaking—were primarily driving the effect. Regardless of patient status or disorganization levels, distractor lines worsened discrimination more in the illusory than the fragmented condition, indicating that all groups could form illusory contours.
Conclusion: People with schizophrenia form illusory contours but are less able to utilize those contours to discern global shape. The impairment is especially related to the ability to think and speak coherently. These results suggest that Kanizsa shape perception incorporates an early illusory contour formation stage and a later, conceptually-mediated shape integration stage, with the latter being compromised in schizophrenia.

1. Introduction

Schizophrenia is a devastating psychiatric disorder characterized by delusions, hallucinations, disorganized thought, bizarre behavior, flat affect, and declines in social, academic, and vocational functioning. Recent studies from brain imaging and visual psychophysics have revealed a constellation of visual abnormalities that are not immediately apparent from the clinician's armchair, ranging from reduced contrast sensitivity (Slaghuis, 1998) to weaker three-dimensional depth illusions (Emrich, 1989; Keane, Silverstein, Wang, & Papathomas, 2013). In the last 30 years, and especially in the last 10 years (Silverstein & Keane, 2011; Uhlhaas & Silverstein, 2005), it has become increasingly apparent that schizophrenia impairs *perceptual organization*—the process whereby coherent and persisting object representations are derived from spatiotemporally fragmented retinal images. As examples, when faces or line drawings are shown in degraded fashion, persons with schizophrenia are worse than healthy controls at identifying those stimuli (Doniger, Foxe, Murray, Higgins, & Javitt, 2002); and when presented with a scattered array of oriented elements (Gabors), patients are less adroit at representing a subset of those Gabors as forming a single contour (Silverstein et al., 2009, 2012; Silverstein, Kovács, Corry, & Valone, 2000). The deficit can also lead to a paradoxical performance *advantage* whenever perceptual organization renders the task more difficult, as with size contrast illusions (Silverstein et al., 2013; Tibber et al., 2013; Uhlhaas, Phillips, Mitchell, & Silverstein, 2006).

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An unresolved issue is why perceptual organization impairment arises in schizophrenia. Does it occur as a result of a dysfunction of lateral connectivity in early visual cortex, as some have maintained (Kéri, Kelemen, Janka, & Benedek, 2005; Robol et al., 2013; Dakin et al., 2005)? Or does it instead arise from higher order circuits, perhaps from faulty feedback from frontal and parietal regions (Keane, Silverstein et al., 2012)? We investigated this question with a classic "Kanizsa" square stimulus, in which four white sectored circles form a darkened surface bounded by illusory contours. Kanizsa shapes make for nearly ideal test stimuli: the eliciting conditions have been extensively documented since the 1950s (Geisler, Perry, Super, & Gallogly, 2001; Kanizsa, 1955; Kellman & Shipley, 1991; Lesher & Mingolla, 1993) and the neural underpinnings of the process have been investigated non-clinically with a variety of techniques including EEG, fMRI, single-cell recording, and TMS (Lee & Nguyen, 2001; Maertens, Pollmann, Hanke, Mildner, & Moller, 2008; Murray et al., 2002; Wokke, Vandenbroucke, Scholte, & Lamme, 2013), revealing a critical role of feedback from LOC and long-range horizontal connections in V1/V2 (Seghier & Vuilleumier, 2006). Moreover, a key component process of illusory shape perception—contour completion (or contour interpolation)—is important in its own right, allowing species throughout the animal kingdom to extract object shape and number (Nieder, 2002).

1.1. EEG studies of Kanizsa shape perception in schizophrenia

The neurobiological substrate and time course of Kanizsa shape perception in schizophrenia have been studied with the scalp-recorded electroencephalogram (EEG), but the results have not always been consistent. Spencer et al. (2003) had observers discriminate Kanizsa shapes from featurally similar fragmented configurations, and measured stimulus-locked phase locking, which records EEG phase variance at a fixed duration after stimulus onset. Healthy controls, but not patients, evinced an early evoked gamma band response (72–98 ms) over occipital electrodes when responding to illusory vs. fragmented shapes. In a follow-up study, "response-locked phase locking"—measured backward in time from a subject's button press—was greater for the illusory than the fragmented stimulus for both groups. However, the difference arose at a higher frequency for controls than patients (31–44 Hz vs. 22–24 Hz) (Spencer et al., 2004). The reduced oscillation frequency was considered to reflect disrupted early "feature-binding" (though see below).

Foxe, Murray, and Javitt (2005) applied a virtually identical behavioral paradigm as above, but analyzed high density visual evoked potentials (VEPs) rather than oscillations. They found that the N1 component (106–194 ms) was enhanced for the illusory relative to the fragmented stimulus for patients and controls. It was thereby argued that illusory contour formation is intact in schizophrenia. The interpretation is plausible given that: (i) the N1 component reflects ventral stream processing, especially in the lateral occipital complex, a primary locus for illusory contour formation (Doniger et al., 2002; Halgren, Mendola, Chong, & Dale, 2003; Mendola, Dale, Fischl, Liu, & Tootell, 1999; Murray, Foxe, Javitt, & Foxe, 2004; Murray et al., 2002); and (ii) the N1 time frame corresponds to the period in which illusory contours form in behavioral and neurophysiological studies (Gold & Shubel, 2006; Guttman & Kellman, 2004; Keane, Lu, & Kellman, 2007; Lee & Nguyen, 2001; Ringach & Shapley, 1996).

Importantly, both sets of studies left open the possibility of abnormal high-level contributions to Kanizsa shape perception. Foxe et al. (2005) unexpectedly found greater right inferior frontal activation among patients in the time period of the so-called N_{Cl} waveform (240–400 ms), an established signature of perceptual closure (Butler et al., 2013). Spencer et al. (2004) discovered that the two strongest clinical correlates of reduced response-locked phase locking were global thought disorder ($r=.61$) and one of its components, conceptual disorganization ($r=.58$). These symptom correlates were estimated on the basis of how clearly a patient communicated during a clinical interview (see below) and suggest that Kanizsa shape perception is at least associated with higher order cognition (Silverstein et al., 2013; Uhlhaas et al., 2006). Spencer and colleagues also acknowledge that reduced synchrony over occipital electrodes could be ascribed to an aberrant high-level template matching process in which a configuration is recognized as a target.

Importantly, behavioral results from the above EEG studies could not settle whether perceptual differences exist in schizophrenia. Lower patient accuracy in the discrimination task (as in Spencer et al., 2003, 2004) could be blamed on generalized deficits—that is, reduced attention or motivation. Normal patient accuracy (as in Foxe et al., 2005) could be explained by ceiling effects, since the task was extremely straightforward and the stimuli so distinct. Therefore, considered jointly, the above EEG studies have not made it clear whether Kanizsa shape perception deficits exist in schizophrenia, let alone the level at which such deficits arise. What is needed, and what we provide here, are the first psychophysical data that directly address this issue.

1.2. Establishing and understanding illusory shape perception deficits in SZ

We probed Kanizsa shape perception with a variation of Ringach and Shapley's (1996) "fat/thin" shape discrimination task, which has been extensively employed to understand perceptual development (Hadad, Maurer, & Lewis, 2010), modal and amodal completion (Kellman, Garrigan, Shipley, & Keane, 2007), completion speed (Guttman & Kellman, 2004) and autism (Milne & Scope, 2008), among other issues. On each trial of our experiment, subjects discriminated the orientations of four sectored circles or pac-men (Gold, Murray, Bennett, & Sekuler, 2000; Gold & Shubel, 2006; Guttman & Kellman, 2004; Keane et al., 2007; Murray, Sekuler, & Bennett, 2001; Pillow & Rubin, 2002; Ringach & Shapley, 1996; Zhou, Tjan, Zhou, & Liu, 2008). In the illusory condition, the sectored circles jointly formed a Kanizsa square, and subjects decided whether the elements formed a fat or thin shape (see Fig. 1A). In a control ("fragmented") condition, the sectored circles faced downward to prevent illusory contours, and the task was to discern whether the elements were each rotated left or right. These two conditions have sometimes been described as differing by a geometric property, "relatability", which governs when elements can and cannot connect via interpolation (Kellman & Shipley, 1991). Half of the trials involved distractor lines, which disrupt illusory contour formation and worsen illusory shape discrimination (Dillenburger & Roe, 2010; Keane, Lu, Papathomas, Silverstein, & Kellman, 2012, 2013; Ringach & Shapley, 1996; Zhou et al., 2008). Task difficulty depended on pac-man rotational magnitude, with larger rotations making the alternatives easier to distinguish. An adaptive staircase determined the difficulty for a trial and estimated the amount of rotation needed to achieve threshold accuracy (79.7%).

Two metrics were of interest. One is *global shape integration*, which corresponds to how well subjects distinguish Kanizsa shapes relative to featurally similar fragmented shapes (without distractors). A lower relative threshold in the illusory condition demonstrates an enhanced capacity to take advantage of the Gestalt layout of the stimulus. Also of interest was how well subjects *fill-in* illusory contours. Filling-in was gauged by how much subjects responded to seemingly irrelevant information (distractor lines) placed near the filled-in paths. The underlying assumption was that the more that subjects fill-in illusory