Psychiatry Research 226 (2015) 441–445

Contents lists available at ScienceDirect

Psychiatry Research

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

Crowding, grouping, and gain control in schizophrenia

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ARTICLE INFO

Article history:
Received 7 August 2014
Received in revised form
6 January 2015
Accepted 11 January 2015
Available online 31 January 2015

Keywords:
Crowding
Schizophrenia
Gain control
Grouping
Contextual modulation

ABSTRACT

Visual paradigms are versatile tools to investigate the pathophysiology of schizophrenia. Contextual modulation refers to a class of paradigms where a target is flanked by neighbouring elements, which either deteriorate or facilitate target perception. It is often proposed that contextual modulation is weakened in schizophrenia compared to controls, with facilitating contexts being less facilitating and deteriorating contexts being less deteriorating. However, results are mixed. In addition, facilitating and deteriorating effects are usually determined in different paradigms, making comparisons difficult. Here, we used a crowding paradigm in which both facilitation and deterioration effects can be determined all together. We found a main effect of group, i.e., patients performed worse in all conditions compared to controls. However, when we discounted for this main effect, facilitation and deterioration were well comparable to controls. Our results indicate that contextual modulation can be intact in schizophrenia patients.

1. Introduction

The obvious symptoms of schizophrenia are hallucinations, delusions, and cognitive dysfunctions. However, schizophrenia patients have many other abnormalities, including visual impairments (Kraepelin, 1893; Chapman, 1966; Silverstein and Keane, 2011; Chen, 2011). Visual paradigms are versatile tools of schizophrenia research because patients' deficits are often very pronounced (Espeseth et al., 2007; Chkonia et al., 2010; Silverstein and Keane, 2011; Bakanidze et al., 2013).

One class of interesting visual paradigms relates to contextual modulation, where perception of a target is strongly influenced by surrounding elements. For example, all spatial illusions are versions of contextual modulation. Other examples are surround suppression, contour integration, and crowding, which all are abnormal in schizophrenia patients. Dakin et al. (2005) presented a medium contrast patch together within a high-contrast surround. Controls perceived the patch as of much lower than the true contrast. In schizophrenia patients this effect was strongly diminished, i.e., patients reported a value closer to the *true* contrast. Interestingly, contrast discrimination itself is strongly deteriorated in schizophrenia patients (Slaghuis, 1998; Keri et al., 2002). Another example of contextual modulation is crowding, where perception of a target deteriorates when flanked by neighbouring elements (see Fig. 1). As in the previous paradigm, patients show less interference by the neighbouring elements (Robol et al., 2013).

Contextual modulation is usually explained by interactions between neighbouring neurons that mutually influence each other, for example via gain control or long range excitation, which are proposed to be weaker than in controls (e.g., Butler et al., 2008; Phillips and Silverstein, 2013). Accordingly, it seems that contextual modulation is in general weaker in patients, i.e., patients benefit less from helpful contexts but are also less affected by deleterious ones (Robol et al., 2013). These diminished neural interactions are also in agreement with the broader claim that contextual processing is deteriorated in general, including in non-visual examples such as verbal and cognitive context memory (e.g., Phillips and Silverstein, 2003; Uhlhaas et al., 2006; Phillips and Silverstein, 2013). It might be that all sorts of abnormal contextual modulation are due to higher levels of cognitive disorganisation, as already proposed by Bleuler (1911).

However, the situation is more complex. For example, Tibber et al. (2013) used a similar paradigm to Dakin et al. (2005) mentioned above, together with a paradigm where the

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http://dx.doi.org/10.1016/j.psychres.2015.01.009
0165-1781/

orientation of target lines was modulated by surrounding lines. As in Dakin et al. (2005), contextual modulation for the contrast was weaker in the patients compared to controls but there were no differences in the orientation paradigm. Hence, not all types of contextual modulation are affected in schizophrenia patients (see also Yang et al., 2013). Moreover, Yoon et al. (2009) reported that patients show weaker modulation when target and surround have the same orientation but no differences when they are orthogonal. In addition to mixed findings, results are often hard to interpret because facilitating (release of deterioration) and deteriorating effects are not determined in one, but in different paradigms.

Related to the neural causes, the neural mechanisms of contextual modulation are under debate. For example, we have shown that in healthy participants contextual modulation cannot be explained by simple local interactions between neighbouring neurons. To the contrary, complex Gestalt aspects determine processing (e.g., crowding: Malania et al., 2007; Pelli and Tillman, 2008; Whitney and Levi, 2011; Manassi et al., 2012; surround modulation: Saarela and Herzog, 2008; visual masking: Herzog and Fahle, 2002). Particularly interesting is crowding, where we developed a task which allows one to test contextual facilitation and deterioration within one paradigm. We presented a vernier, which comprises two vertical bars that are offset slightly either to the left or right. Observers indicated the offset direction. Performance strongly deteriorated when the vernier was flanked by arrays of lines of the same length as the vernier (Fig. 1). This is a classic crowding effect. However when we presented arrays of shorter or longer lines, performance improved, challenging most models of crowding and of contextual modulation in general. Particularly, models cannot explain why longer lines, with more stimulus energy, improve performance compared to the equal length condition (e.g., Malania et al., 2007; Manassi et al., 2012). We proposed that grouping, rather than low level mechanisms, determine crowding. When the vernier groups with the flankers (same length lines) crowding is strong. When the vernier ungroups from the flankers grouping is weaker (shorter or longer lines).

Here, we applied this paradigm to schizophrenia patients. Patients performed worse compared to controls in all conditions. However, when we discounted for this main effect of group, patients performed similarly as controls, indicating that contextual modulation is intact.

2. Methods

2.1. Participants

Sixteen schizophrenia patients and 15 healthy controls participated in this study. All observers had normal or corrected-to-normal vision i.e., visual acuity was ≥ 0.8 (corresponding to 20/25) at least in one eye, as determined with the Freiburg Visual Acuity Test (Bach, 1996).

Schizophrenia patients were recruited from the Tbilisi Mental Health Hospital or the psycho-social rehabilitation centre where they had been admitted because of an acute episode of their disease. They were invited to participate in the study when they had recovered sufficiently and were estimated to be able to endure the study procedure. Among the patients group, there were three inpatients and 13 outpatients. Healthy controls were recruited from the general population. General exclusion criteria were drug or alcohol abuse, neurological or other somatic illnesses influencing subjects' mental state. Participants were no older than 55 years.

Ethics approval was obtained in Tbilisi from the Georgian National Council on Bioethics. All subjects signed informed consent and were informed that they could quit the experiments at any time.

Patients were diagnosed according to DSM-IV, by means of an interview based on the SCID, information of the staff, and the study of the records. Psychopathology of the schizophrenia patients was assessed by an experienced psychiatrist (EC) by Scales for the Assessment of Negative Symptoms and Scales for the Assessment of Positive Symptoms (SANS, SAPS (Andreasen, 1983, 1984). Group characteristics are depicted in Table 1.

All patients were receiving neuroleptic medication. Chlorpromazine equivalents are indicated in Table 1.

2.2. Apparatus and procedure

We determined thresholds for vernier offset discrimination. Verniers were presented alone or neighboured by flanker configurations. Verniers consisted of two vertical lines slightly offset to the left or right. The task of the observers was to discriminate the vernier offset direction.

The experimental room was dimly illuminated 0.5 lx Stimuli were generated on a Pentium-based computer and displayed on a Siemens Fujitsu P796–1 monitor (31.0 cm (H) $\times$ 23.3 cm (V), 1024 $\times$ 768 resolution). White stimuli were presented on a black background and the luminance of the screen was below 1 cd/m^2. Luminance of stimuli was 100 cd/m^2 approximately. Refresh rate was 100 Hz and viewing distance was 350 cm.

The vernier consisted of two vertical 10′ (arcmin) long lines separated by a vertical gap of 1′. Observers were instructed to fixate the vernier. Vernier and flankers were presented simultaneously for 150 ms.

Observers were asked to indicate the vernier offset direction by pressing one of two push buttons. Auditory feedback was provided after incorrect or omitted responses. An adaptive staircase procedure (Taylor and Creelman, 1967) was used to determine the threshold for which observers reached 75% correct responses. Thresholds were determined after fitting a cumulative Gaussian to the data using probit and likelihood analyses. The starting offset was 1.67′.

After each trial, the screen remained blank for a maximum period of 3 s during which the observer was required to make a response. The screen was blank for 400 ms between the response and the next trial. In every block of 80 trials, the number of left and right offsets was balanced.

2.3. Stimulus configurations

The vernier was presented alone or flanked by two arrays of 16 vertical lines, one on each side (Fig. 1). The directly neighbouring lines were always placed at a distance of 3.33′ from the vernier. Inter-flanker spacing was also 3.33′. Three different flanker lengths were used: short (5′), equal (10.5′), and long (21′) (Fig. 1). Each condition was presented in separate blocks of 80 trials. All conditions, including the vernier alone condition, were measured twice (i.e., 160 trials in total). The order of the flanker and vernier configurations was randomized across observers. To compensate for potential learning effects, performance in all conditions was measured once and then, the order of conditions was reversed in the second run.

3. Results

First, we performed a 2×4 repeated measures analysis with Group as between-subjects factor (patients vs. controls) and Condition as within-subjects factor (unflanked, equal size flankers, short size flankers, long size flankers). There was a significant effect of Condition ($F[1,55] = 12.6$; $p \leq 0.0005$), where performance was best in the unflanked condition and worst in the equal sized flankers condition, reproducing previous results. There was no significant interaction. Schizophrenia patients had, on average, higher thresholds than controls in all conditions ($F[1,29] = 56.3$; $p \leq 0.0005$). For example, mean thresholds for the unflanked vernier discrimination were 16.2′ $\pm$ 8.6 and 27.0′ $\pm$ 13.1 in controls and patients, respectively. To account for this base deficit, we normalised performance by dividing the “crowding” threshold for each observer by his/her threshold in the unflanked condition, i.e., we determined performance in terms of threshold elevation. These values were subjected to a 2×3 repeated measures ANOVA with factors Group (patients, controls) and Condition (equal size, short size, long size flankers). There was a main effect of Condition ($F[1,42] = 11.9$; $p \leq 0.0005$) but no significant main effect of group ($F[1,29] = 0.02$; $p = 0.9$) and no significant interaction ($F[1,42] = 0.2$; $p = 0.75$).

Hence, there is nonspecific deterioration of patients in all conditions. When this effect is controlled for, performance of patients is about on the same level as the one for controls.