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Altered center-surround motion inhibition in schizophrenia

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Abstract

Background—Schizophrenia is a brain disorder that spans across biological and behavioral levels. The links between altered neural circuitry and abnormal behaviors are yet to be understood. Visual motion perception has been established in basic neuroscience and may provide an opportunity to link different levels of brain functions in schizophrenia. Center-surround interaction is a ubiquitous neural mechanism underlying the organization of visual information over different spatial locations.

Methods—We applied a psychophysical paradigm to examine center-surround interaction in schizophrenia. Patients ($n=24$) and controls ($n=33$) judged the direction of a moving random dot pattern (RDP, center), with and without the presence of another concentric surrounding RDP (surround)

Results—The presence of a moving surround shifted the perceptual judgments of center motion in the opposite direction from the surround in both subject groups, but the magnitude of the perceptual shift was significantly larger in patients. The increased perceptual shift was not correlated with psychotic symptoms, which were mild in this patient sample, or antipsychotic medication.

Conclusions—The increased perceptual shift suggests that the putative surround suppression on visual motion perception is abnormally increased in schizophrenia. This result provides perceptual evidence for altered basic inhibitory control of visual motion context in schizophrenia.

Keywords

schizophrenic; visual motion; spatial interaction; perception; neural suppression

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A critical question in understanding the pathophysiology of schizophrenia concerns how altered neural circuitry [1–3] leads to abnormal behaviors in patients [4,5]. To answer this question, it is useful to focus on those perceptual responses whose neurobiological bases have been established. Motion perception is such a response as it is controlled by basic neural computation and has been extensively studied physiologically and psychologically.

Schizophrenia patients showed deficient visual discrimination of motion directions [6,7] and speeds [8–10]. While the perceptual deficit presumably involves the extrastriate cortex, the exact underlying neural mechanisms have not been systematically examined. Center-surround interaction plays a fundamental role in organizing spatially distributed signals for perception. In the visual system, center-surround interaction is generally characterized by (1) suppression and (2) facilitation of surround on neural response to central motion [11]. The neural responses are suppressed by a surround containing the same direction of motion as the center, and are

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facilitated by a surround containing the opposite direction of motion to the center [12]. Perceptual responses to visual motion are mediated by direction-selective neural units; e.g. those selective to rightward direction are responsible for forming a percept of rightward motion. The consequence of surround suppression is a perceptual shift towards the opposite direction of central motion [13].

Examination of how motion signals in distinct spatial locations interact allows inference about the level and specificity of the neural mechanism(s) that may be implicated in schizophrenia. In this study, we controlled stimuli presented in the surround (moving vs. static, leftward vs. rightward motion) independently of the center, and measured motion perception in the center. When the center and the surround moved in the same direction, decreased surround suppression would yield a perceptual shift towards the direction of central motion whereas increased surround suppression would yield an additional perceptual shift towards the opposite direction. When the center and the surround moved in opposite directions, decreased and increased surround facilitation would yield a perceptual shift towards the opposite and the same direction of central motion, respectively. Given that decreased surround suppression in schizophrenia was reported [14,15], we hypothesize that patients would show a perceptual shift towards central motion.

Motion perception involves neural interaction of visual signals across space and time. With this unique feature, studying the center-surround mechanism in connection with motion perception should yield insights into the relationship between altered neural organization and abnormal perceptual response in schizophrenia.

Methods

Subjects

Participants included 24 schizophrenia patients and 33 normal controls. Diagnoses for patients were conducted based on a structured clinical interview (DSM IV) and a review of all available medical records. The absence of axis I psychiatric disorders for controls was assessed using a standardized interview based on SCID-I/NP. Table 1 provides demographic information for the participants. Table 2 provides clinical information for the patients.

Stimulus

The target for motion discrimination, the center, was a random dot pattern (RDP) that contained two components. The signal component was a group of dots moving coherently in one direction (left or right) and the noise component was another group of dots moving in random directions. The two components were interleaved spatially within a circular window (Fig 1). The surround was a concentric RDP containing only the signal component or static dots (Fig 1). Subjects reported their judgments about the direction of motion in the center.

Results

Moving surround

The presence of a moving surround shifted motion perception in controls and, to a greater extent, in patients, as indicated by changed proportions of trials reported as 'rightward' (Fig 2). To compare the magnitudes of the perceptual shift between groups, we used the difference of the proportions of trials reported as 'rightward' when the surround was and was not present (Fig 3). ANOVA (group, coherence and surround direction) showed that the perceptual shift was significantly greater (1) in patients than in controls ($F = 28.67$, $p < 0.001$) and (2) when the surround moved in the same direction as central motion, as opposed to the opposite direction ($F = 10.22$, $p = 0.002$). The group difference appeared to be greater when the center and the

surround moved in the same directions yet the interaction between surround direction and group did not reach a statistically significant level ($F = 3.53$, $p = 0.06$). In both groups, the perceptual shift was greatest when central and surrounding motion moved in the same direction, and at 40% coherence (Fig 3).

The perceptual shift was not correlated with perception of central motion or with the low level of psychotic symptoms or antipsychotic medications (Supplement).

Static Surround

ANOVA (coherence and group) showed that perceptual shift did not differ significantly between the groups ($F = 0.435$, $p = 0.51$), and differed significantly across coherence levels ($F = 2.16$, $p = 0.019$). The group-coherence interaction was not significant ($F = 1.17$, $p = 0.31$) (Fig 4).

Discussion

The finding of an increased perceptual shift in patients suggests that center-surround interaction is altered in schizophrenia. The directional specificity of the increased perceptual shift, i.e., occurring mostly when the center and surround moved in the same direction (Fig 3), suggests that alteration of center-surround interaction is primarily due to a stronger suppression rather than facilitation from surround [12].

The increased surround suppression points to an excessive inhibitory control of motion processing, likely mediated by GABAergic neurotransmission, in the associated neural circuitries [16]. Studies in aging found age-associated decreases in GABA mediated inhibition [17] and reduced surround suppression on motion perception [18]. The increased surround suppression, found in this study, and the reduced surround suppression, found in a previous study, in schizophrenia suggest that abnormalities in inhibitory control of motion processing are multi-faceted in nature [14,19].

The perceptual shift in patients peaked at intermediate to high levels of motion coherence (Fig 3). The dependence of surround modulation on signal strength is analogous to the finding that center-surround interaction in schizophrenia is weakened for high contrast stimuli [14]. Both results suggest that suppressive surround modulation is abnormal in schizophrenia when salient motion stimuli (such as those with high contrast or intermediate motion coherence) adequately activate the neural circuitry.

Our results and those from previous studies seem to differ regarding the nature of abnormal suppression. In a previous study [14], controls, but not patients, were less sensitive in detecting a large sized moving grating. Since only large-sized stimuli activate the center-surround mechanism, this result suggests that the center receives less suppression from the surround in schizophrenia (i.e. weakened surround suppression). In another study [15], contrast perception in patients was less affected by the presence of a surround, suggesting weak surround suppression. The present study showed that the presence of a moving surround induced an additional perceptual shift towards the *opposite* direction of central motion in patients, suggesting stronger surround suppression. One potential interpretation for the seeming inconsistency would be to consider the different processing stages involved. The previous studies focused on processing of localized information (gratings), whereas the present study focused on processing that depends heavily on spatial integration (random dots patterns). Patients' heightened sensitivity to local motion [14] could provide an amplified input to global processing. The increased response to *surround* motion at the global processing stage might yield stronger modulation and result in an increased perceptual shift towards the opposite direction of central motion. This speculation needs to be examined empirically, perhaps by

asking whether the heightened-sensitivity to local motion stimuli in patients is related to their increased perceptual shift for global motion stimuli.

The increased perceptual shift in patients could be influenced by altered top-down control in filtering out the 'irrelevant' surround, although the direction specificity of the result does not favor this interpretation. Another factor could be decreased surround facilitation since the increased perceptual shift in patients was present also when the center and the surround moved in opposite directions. However, the magnitude of the effect was relatively small (Fig 3), suggesting that decreased surround facilitation or altered motion opponency between suppression and facilitation plays a minor role.

Patients show impaired performance in tasks ranging from perceptual contour integration [4] to detection of a hierarchical stimulus [20]. A common thread here is the requirement for spatial integration. The altered center-surround interaction in patients raises the question whether the complex cognitive impairments involve elementary computation (suppression and facilitation). Either way, the altered center-surround interaction may provide poorly processed sensory signals for those cognitive responses that require spatial organization.

Moving but not static surrounds modulate neural responses in the Middle Temporal area (MT) whereas both types of surrounds modulate neural responses in the Medial Superior Temporal area (MSTi). Given that this type of stimuli activates primarily MT and MST areas, little effect of static surround (Fig 4) suggests that altered interaction between moving surround and the center in patients is likely, though not definitely, associated with MT.

In summary, this study found abnormally increased surround suppression on motion perception in patients. The result presents a perceptual manifestation of altered center-surround motion inhibition in schizophrenia.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

1. Coyle J. The glutamatergic dysfunction hypothesis for schizophrenia. *Harvard Review of Psychiatry* 1996;5:241–253. [PubMed: 9384954]
2. Benes FM. Emerging principles of altered neural circuitry in schizophrenia. *Brain Research Brain Research Reviews* 2000;31(2–3):251–269. [PubMed: 10719152]
3. Frankle WG, L J, Laruelle M. The synaptic hypothesis of schizophrenia. *Neuron* 2003;39:205–216. [PubMed: 12873379]
4. Phillips WA, Silverstein SM. Convergence of biological and psychological perspectives on cognitive coordination in schizophrenia. *Behav Brain Sci* 2003;26(1):65–137. [PubMed: 14598440]
5. Andreasen NC. A unitary model of schizophrenia: Bleuler's "fragmented phrene" as schizencephaly. *Archives of General Psychiatry* 1999;56:781–787. [PubMed: 12884883]
6. Stuve T, Friedman L, Jesberger JA, Gilmore GC, Strauss ME, Meltzer HY. The relationship between smooth pursuit performance, motion perception and sustained visual attention in patients with schizophrenia and normal controls. *Psychological Medicine* 1997;27(1):143–152. [PubMed: 9122294]

7. Chen Y, Nakayama K, Levy DL, Matthyse S, Holzman PS. Processing of global, but not local, motion direction is deficient in schizophrenia. *Schizophrenia Research* 2003;61(2–3):215–227. [PubMed: 12729873]
8. Chen Y, Nakayama K, Levy DL, Matthyse S, Holzman PS. Psychophysical isolation of a motion-processing deficit in schizophrenics and their relatives and its association with impaired smooth pursuit. *Proceedings of the National Academy of Sciences* 1999;96(8):4724–4729.
9. Kim D, Wylie G, Pasternak R, Butler PD, Javitt DC. Magnocellular contributions to impaired motion processing in schizophrenia. *Schizophrenia Research* 2006;82(1):1–8. [PubMed: 16325377]
10. Chen Y, Levy DL, Sheremata S, Holzman PS. Compromised late-stage motion processing in schizophrenia. *Biological Psychiatry* 2004;55(8):834–841. [PubMed: 15050865]
11. Kuffler S. Neurons in the retina; organization, inhibition and excitation problems. *Cold Spring Harbor Symposia on Quantitative Biology* 1952;17:281–292.
12. Born R. Center-surround interactions in the middle temporal visual area of the owl monkey. *J Neurophysiol* 2000;84:2658–2669. [PubMed: 11068007]
13. Murakami I SS. Assimilation-type and contrast-type bias of motion induced by the surround in a random-dot display: evidence for center-surround antagonism. *Vision Res* 1996;36:3629–3639. [PubMed: 8976993]
14. Tadin D, Kim J, Doop ML, Gibson C, Lappin JS, Blake R, Park S. Weakened center-surround interactions in visual motion processing in schizophrenia. *J Neurosci* 2006;26:11403–11412. [PubMed: 17079669]
15. Dakin S CP, Hemsley D. Weak suppression of visual context in chronic schizophrenia. *Current Biology* 2005;15:R822–R824. [PubMed: 16243017]
16. Egelhaaf M, Borst A, Pilz B. The role of GABA in detecting visual motion. *Brain Research* 1990;509(1):156–160. [PubMed: 2306632]
17. Leventhal AG WY, Pu M, Zhou Y, Ma Y. GABA and its agonists improved visual cortical function in senescent monkeys. *Science* 2003;300:812–815. [PubMed: 12730605]
18. Betts LR, T C, Sekuler AB, Bennett PJ. Aging reduces center-surround antagonism in visual motion processing. *Neuron* 2005;45:361–366. [PubMed: 15694323]
19. Bidwell LC, Holzman PS, Chen Y. Aging and motion discrimination in normal adults and schizophrenia patients. *Psychiatry Research* 2006;145:1–8. [PubMed: 17069895]
20. Johnson SC, L N, Kohler C, Turetsky BI. Global-local visual processing in schizophrenia: evidence for an early visual processing deficit. *Biological Psychiatry* 2005;58(12):937–946. [PubMed: 16084856]

Figure 1.

Schematic illustration of the stimulus configuration. The random dot pattern (RDP, center) contains 1) dots moving coherently along one direction (e.g. right) and 2) dots moving in random directions. Stimulus duration was 390 msec. The proportion of the trials reported as rightward motion was measured as a function of the 11 motion coherence levels ($0, \pm 5, \pm 10, \pm 20, \pm 40$, and $\pm 100\%$, with negative values indicating leftward direction, and positive values indicating rightward direction, and 3 types of surround (leftward, rightward, and static). The size of the center was 7 degrees in diameter. All dots, except for those in a static surround, moved at 7 degrees/sec. The size of the outer boundary of the concentric surround was 14 degrees.

Figure 2.

Perceptual responses to the center RDP under three conditions: a) the absence of a surround, b) the presence of a rightward surround, and c) the presence of a leftward surround. The surround has a concentric diameter of 14 degrees. Perceptual responses are measured by the proportions of trials reported as 'rightward'. For each surround condition, equal numbers of left and rightward trials were presented across a series of coherence levels. Data from normal controls and schizophrenia patients are displayed in the top and the bottom panels, respectively. In both panels, the ordinates represent the proportions of trials reported as 'rightward'. The abscissa represent the motion coherence levels of the center. Open symbols, connected by the dotted lines, are for the no surround condition whereas gray symbols and black symbols,

connected by solid lines, are for the rightward and the leftward surround conditions, respectively. Error bars indicate ± 1 standard error.

Figure 3.

Perceptual shift in the presence of a moving surround. Perceptual shift is defined by the difference between the proportions of trials reported as 'rightward' in the presence and in the absence of the surround. Since leftward and rightward surrounds produced nearly symmetrical shift effects (mostly towards the direction opposite to the surround), the data from these two surround conditions were combined. For the physiological reasons described in Introduction and Discussion, the perceptual shift was computed according to whether the center and the surround contained the same (bottom panel) vs. the opposite (top panel) directions of motion. For the same directions of motion, the perceptual shifts for the rightward central motions (+5%, +10%, +20%, +40%, +100%) and the rightward surround are averaged with those for the

leftward central motions (-5% , -10% , -20% , -40% , -100%) and the leftward surround. For the opposite directions of motion, the perceptual shifts for the rightward central motions ($+5\%$, $+10\%$, $+20\%$, $+40\%$, $+100\%$) and the leftward surround are averaged with those for the leftward central motions (-5% , -10% , -20% , -40% , -100%) and the rightward surround. The open symbols are for patients (SZ) whereas the filled symbols are for normal controls (NC). The horizontal zero dotted line in each panel indicates no perceptual shift. The data above the zero line indicate perceptual shift toward opposite directions of central motion. The data below the zero line indicate perceptual shift towards same directions of central motion. Error bars indicate ± 1 standard error.

Figure 4.

Perceptual shift in presence of static surround. The static surround is identical to the moving one except that the dots in the former do not move. For other information of the format, see legend of Figure 3.

Table 1**Subject demographic information**

Means are reported above SD in parentheses.

Group	Age (years)	Sex	Verbal IQ*	Education (years)*
Schizophrenia (n=24)	41.1 (9.4)	F - 11 M - 13	105.5 (12.7)	14.5 (1.8)
Normal Control (n=33)	35.8 (12.8)	F - 16 M - 17	112.8 (9.9)	16.4 (1.8)

Asterisks represent statistically significant group differences ($p < 0.05$). The two groups were matched on average age and sex.

Table 2**Clinical information of the patient sample (mean (SD))**

The patients were recruited from a private psychiatric hospital; 10 of them had a diagnosis of schizophrenia and 14 patients had a diagnosis of schizoaffective disorder.

Illness duration (year)	19.2 (10.5)
Remission status	15 outpatients, 9 inpatients;
PANSS - positive	16.0 (7.6)
PANSS - negative	13.9 (6.2)
PANSS - general	31.3 (11.2)
CPZ (mg)	554.2 (409.2)