Visual selective attention among persons with schizophrenia: The distractor ratio effect

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Abstract

The current study investigated whether impaired visual attention among patients with schizophrenia can be accounted for by poor perceptual organization and impaired search selectivity. Twenty-three patients with schizophrenia and 22 healthy control participants completed a conjunctive visual search task where the relative frequency of the two types of distractors was manipulated. It has been shown that, when the total number of items in a display is fixed, search performance depends on the relative frequency of the types of distractors (i.e., as the ratio becomes more discrepant search time decreases). This modulation of search efficiency reflects participants’ ability to group items by their perceptual similarity and then search only the smaller group of items that share a feature with the target. Results show that patients modulate their response time normally as a function of the distractor ratio – that is, they benefit from the presence of a smaller distractor subset in the display. This suggests that patients with schizophrenia, group items according to their perceptual similarity and flexibly deploy their attention to the smaller subset of distractors on each trial. These results demonstrate that search selectivity as a function of the relative frequency of distractors is unimpaired among patients with schizophrenia.

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1. Introduction

1.1. The visual search paradigm

In the past three decades, the visual search paradigm has been widely used in the study of visual attention. In a typical “conjunctive” visual search task, participants are required to search for a target item among a number of nontarget items (i.e., distractors). Each of the distractors shares one of its features (e.g., color) with the target item and there exists an equal number of each type of distractor in the display. Often the total number of items in the display (i.e., display size) is manipulated and search efficiency is determined by measuring the change in response time (RT) or error rate (ER) as a function of display size. When search is highly efficient, plotting RT as a function of display size yields a flat
slope, suggesting that search is executed in parallel across the whole display. Search slopes increase as search becomes more serial and elaborate, that is, less efficient (see Treisman, 1988 for a review). It has been demonstrated that the discriminability of the target from the distractors is the main factor in search efficiency (Duncan and Humphreys, 1989). However, visual search also achieves efficiency through other mechanisms. For example, studies have shown that, during conjunctive visual search, display items are often parsed into groups of items. This phenomenon has been referred to as perceptual grouping and is defined as the preliminary perceptual segregation of the stimulus field prior to the application of focused attention (Treisman, 1982). Items in a display can be grouped based on different principles such as similarity (Baylis and Driver, 1992; Kramer and Jacobson, 1991), contiguity (Moore et al., 1998), and co-linearity (Lavie and Driver, 1996). Perceptual grouping improves search efficiency by enabling a person to focus attention on groups rather than single items in the display and select the most informative items for further search. This reduces the need to scan each individual item in a conjunctive search display. So, for example, in the search for a green ‘X’ among red ‘X’s and green ‘O’s a person might limit their search to either the green items that share the target color or the ‘X’s that share the target shape. When there is an equal number of each type of distractor, often search is limited to the subset of items that has the more dominant feature. For example, if their color is more discriminable, search is limited to the same-color items. However, previous studies have also shown that subset selection can occur based on the relative frequency (i.e., ratio) of the two types of distractors. That is, when the relative frequency of distractors is manipulated during conjunctive visual search tasks, there is a bias to search through the smaller subset of distractors (Shen et al., 2000). Shen et al. investigated the eye movements of participants during a conjunctive visual search task in the attempt to explain the distractor ratio effect - the finding that when the total number of items in a search display is fixed, search performance in a conjunctive visual search task depends on the relative frequency of the two types or subsets of distractors (Bacon and Egeth, 1997; Egeth et al., 1984; Kaptein et al., 1995; Poisson and Wilkinson, 1992; Zohary and Hochstein, 1989). The distractor ratio effect results in optimum search efficiency for displays with extreme distractor ratios (i.e., one of the distractors is rare), but search efficiency decreases as the ratio of distractors approaches one (i.e., the two types of distractors are equally represented). Consequently when RT is plotted as a function of the number of one type of distractor, an inverted U (or V) pattern emerges. The distractor ratio effect is an excellent example of visual selective attention and visual guidance flexibility during visual search. It has also been found that this type of visual guidance is mostly under the control of lower level, bottom-up, factors and is affected but not overridden by top-down factors such as contextual or instructional manipulations (Shen et al., 2007).

1.2. Visual search in schizophrenia (SCZ)

The majority of studies investigating visual search performance among SCZ patients have found that patients are less efficient on visual search tasks. That is, patients demonstrate steeper search slopes compared to controls on conjunctive search tasks (Carr et al., 1998; Fuller et al., 2006; Mori et al., 1996). As noted above, visual search efficiency in the context of a conjunctive search task depends, in part, on the ability to group perceptually similar items together and direct attention to the most relevant and informative group of items in the display. Therefore, impairment in perceptual grouping may be one mechanism underlying impaired visual search performance among SCZ patients.

1.3. Perceptual grouping in SCZ

Empirical evidence suggests that SCZ is associated with an impairment in the early stages of perceptual information processing, specifically a deficit in perceptual organization (Place and Gilmore, 1980; Wells and Leventhal, 1984). In general, these findings suggest that patients with SCZ fail to perform an initial global structuring of the stimulus field and, therefore, their performance is not affected by the gestalt information present in the display. However, others have found that patients with SCZ group items normally based on perceptual attributes (Carr et al., 1998; Chey and Holzman, 1997; Rief, 1991). For example, Carr et al. investigated the relationship between RT and the number of groups in a display among SCZ and healthy individuals. According to Treisman and Gelade (1980), as a result of perceptual grouping, RT increases in a linear fashion as the number of groups in a display increases. Carr et al. found that patients with SCZ were influenced by the increase in the number of groups in a manner similar to controls. As such, they concluded that perceptual grouping was intact in patients with SCZ.

As reviewed above, the distractor ratio effect is the result of perceptual grouping with the additional component of selectivity based on the relative frequency
of distractors; that is, in addition to perceptual grouping, the distractor ratio paradigm also tests the ability to make the most efficient selection given the relative frequency of distractors. Moreover, given that the relative frequency of distractors is manipulated across trials, successful performance on this task would often require switching attention to a different type of stimulus on a trial by trial basis necessitating some degree of cognitive flexibility and control, a process that appears to be compromised in SCZ (e.g., Cohen and Servan-Schreiber, 1992). The distractor ratio effect is a robust finding among healthy participants. However, it has never been studied among patients with SCZ.

1.4. Objectives of the current study

The goal of the current study was to investigate patients’ ability to group search items based on perceptual characteristics and to select the most informative stimulus group for further search. Previous research in SCZ has yielded mixed results with regards to perceptual grouping – some studies demonstrating impaired perceptual grouping and others suggesting its integrity. We hypothesize that, if the mechanisms of perceptual grouping and selection based on distractor ratio are impaired in patients, normal modulation of search times as a function of the ratio of distractor types should be absent or minimized. However if these mechanisms are intact in SCZ patients, they should manifest the typical inverted V pattern indicative of a normal distractor ratio effect. Such data would help to further guide hypotheses about the underlying mechanisms of impaired visual attention in this patient population.

2. Methods

2.1. Participants

Twenty-three patients diagnosed with SCZ or Schizoaffective Disorder, according to the Diagnostic and Statistical Manual of Mental Disorders, 4th edition (DSM-IV), and 22 healthy control subjects participated in the study. Patients were recruited from the Schizophrenia Research Registry at the Centre for Addiction and Mental Health (CAMH) and their diagnosis of either SCZ or Schizoaffective Disorder was confirmed by trained graduate students using the Structured Clinical Interview for Diagnosis of DSM-IV Axis I Disorders Patient Edition (SCID-P; First et al., 2001a). All SCZ participants were outpatients, clinically stable and receiving a single antipsychotic medication: 19 patients were receiving second generation antipsychotics and 4 patients were receiving first generation antipsychotics. Patients receiving medication with known cognitive effects such as tricyclic antidepressants, anticholinergics, anticonvulsants, or regular benzodiazepines were excluded from the study. Healthy controls were recruited from the community via newspaper advertisements and matched the patient participants with respect to age and sex. Control participants were confirmed to be free of Axis I psychiatric disorders using the Structured Clinical Interview for Diagnosis of DSM-IV Axis I Disorders Non-Patient Edition (SCID-N/P; First et al., 2001b). In addition, individuals who reported a lifetime history of an Axis I disorder or had a first-degree relative with SCZ or other psychotic disorders were excluded from the control group. All participants were between 18 and 60 years old, had normal or corrected-to-normal visual acuity, normal colour vision, used English as their primary language and reported having acquired English before the age of 5. Individuals were excluded from participating in the study if they reported using illicit drugs within the past month or if they met criteria for lifetime history of substance dependence. They were also excluded if they had a self-reported history of learning disability, neurological injury/disease (including a history of head injury with loss of consciousness more than half an hour), or any other medical condition known to have cognitive effects (e.g., severe heart or pulmonary

Table 1
Demographic and clinical characteristics of the sample (mean and SD or ratio)

<table>
<thead>
<tr>
<th></th>
<th>Patient Participants</th>
<th>Control Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n =23)</td>
<td>(n =22)</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>36.7 (11.8)</td>
<td>35.7 (11)</td>
</tr>
<tr>
<td>Male/Female</td>
<td>16/7</td>
<td>14/8</td>
</tr>
<tr>
<td>Education (yrs)</td>
<td>13.9 (2.2)</td>
<td>15.8 (2.3)*</td>
</tr>
<tr>
<td>Illness Length (yrs)</td>
<td>11.6 (11.3)</td>
<td>N/A</td>
</tr>
<tr>
<td>Hospitalizations</td>
<td>2.9 (4.4)</td>
<td>N/A</td>
</tr>
<tr>
<td>PANSS T-Scores:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Positive</td>
<td>34.25 (4.87)</td>
<td>N/A</td>
</tr>
<tr>
<td>- Negative</td>
<td>41.25 (9.46)</td>
<td></td>
</tr>
<tr>
<td>RBANS Index Scores:a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Immediate</td>
<td>90.15(13.90)</td>
<td>102.40(16.15)*</td>
</tr>
<tr>
<td>- Memory</td>
<td>99.75(17.25)</td>
<td>109.73(13.58)*</td>
</tr>
<tr>
<td>- Visuospatial/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constructional</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Language</td>
<td>88.70(10.44)</td>
<td>101.14(11.08)*</td>
</tr>
<tr>
<td>- Attention</td>
<td>81.10(11.76)</td>
<td>101.86(14.57)*</td>
</tr>
<tr>
<td>- Delayed Memory</td>
<td>90.15(14.29)</td>
<td>104.91(12.74)*</td>
</tr>
</tbody>
</table>

PANSS = Positive and Negative Symptoms Scale; RBANS = Repeatable Battery for the Assessment of Neuropsychological Status; * p < .05 (Standard deviations in parentheses).

a Data are unavailable for 3 patients.
disease, insulin-dependent diabetes, thyroid disease, epilepsy, neurological illness such as Parkinson’s or Huntington’s disease).

The demographic information for the two participant groups is shown in Table 1. The control group was on average 1.9 years more educated than the patient group and had, as expected, higher scores on all RBANS indices. The groups were statistically equivalent across other demographic variables.

2.2. Experimental apparatus

The experiment was designed and built using the Experiment Builder Software (SR Research Ltd.). Stimuli were presented on a 17-inch Viewsonic Professional Series PF775 monitor. A chin-rest was used to keep the participants’ viewing distance fixed at 60 cm from the monitor. Participants used a Targus PAUK10C keypad to indicate their response.

2.3. Stimuli and design

A total of three different stimuli were used to create the visual search displays used in this study: a green ‘X’, a red ‘X’, and a green ‘O’. At a viewing distance of 60 cm, each individual stimulus subtended a visual angle of 0.84° (27 pixels) horizontally and 0.91° (29 pixels) vertically. All stimuli were presented in a 22° × 22° field (704 × 704 pixels) and the minimum distance between the centres of neighboring items was 1.8°. The red and green items were matched in luminance and presented on a white background. The target was always a green ‘X’; therefore, the green ‘O’ served as a same-color distractor while the red ‘X’ served as the same-shape distractor. To eliminate response bias and to reduce the possibility of a speed-accuracy trade-off, the search displays used in this study always contained a target, either on the right or the left half of the display, and the participants were asked to locate the target via a forced-choice format. The total number of stimuli presented in the display was fixed at 48. The relative frequency of the two types of distractors (same-shape/same-color distractors) was manipulated across five possible ratios (0/48, 6/42, 24/24, 42/6 and 48/0). Once the display was generated, one of the distractors was randomly chosen to be replaced by the target stimulus (green X). Therefore, in each display there were a total of 47 distractors. Each participant performed a total of 320 trials, which amounted to 64 trials for each cell of the design (distractor ratio level). The order of the stimulus displays was completely randomized with a restriction that no more than three displays of a given target location (right or left) appeared in a row. At the beginning of the task, the participant received a practice block of 10 trials, with 1 trial for each possible combination of distractor ratio and target location. At the beginning of each trial a fixation cross was presented at the centre of the display. Participants were instructed to fixate on the cross. After 500 milliseconds, the fixation cross disappeared and the search display appeared on the screen. Trials were terminated by participants’ speeded response. The “Enter” key on the keypad was used to indicate a right-sided target presentation and the “0” key was used to indicate a left-sided target presentation. Correct responses were signaled via a bell and errors via a buzzer. Response time, key selection and accuracy were recorded for each trial. Response time was defined as the time between the onset of the stimulus display and the participant’s response.

2.4. Procedure

After acquiring consent and general demographic/clinical information, participants’ vision and color vision was tested using a Snellen acuity chart and the Ishihara color vision test respectively. Next, participants were interviewed using the SCID, after which they completed the visual search task. At the beginning of the task, participants read aloud the instructions and were asked to respond as quickly and accurately as possible. Test trials were presented in 8 blocks of 40 trials each. Rest breaks were allowed between each two blocks as needed. After the completion of the experimental task, a neuropsychological assessment was performed using the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS; Randolph, 1998) Form A. Finally, participants in the patient group were also interviewed using the Positive and Negative Symptoms Scale (PANSS; Kay et al., 1992).

3. Results

Both groups were highly accurate (mean accuracy of above 97.5% for both groups on all levels of distractor ratio). Trials with incorrect responses were removed from the data and each participant’s RT values in each of the distractor ratio levels were examined for the existence of outliers. RT values exceeding three standard deviations from the mean in each condition were eliminated from further analyses. The removed trials amounted to 1.6% and 1.5% of the trials for patients and controls respectively. Median RTs for each individual was calculated for each level of distractor ratio.
ratio and used as a measure of participant’s performance in that condition. A 5(distractor ratio) × 2(group) mixed models ANOVA was performed on the median RTs with distractor ratio as the within-subject factor and group as the between-subjects factor. The ANOVA revealed main effects for group, \( F(1, 43)=21.25, p<.001, \eta_p^2=.33; \) and distractor ratio, \( F(4, 172)=170.8, p<.001, \eta_p^2=.8. \) There was also a significant Distractor Ratio × Group interaction, \( F(4, 172)=6.8, p=.001, \eta_p^2=.14, \) whereby patients with SCZ had disproportionately longer search times at the 24/24 distractor ratio level.

Fig. 1 plots RT as a function of the number of same-shape distractors and suggests that both groups were slowest when there were an equal number of same-shape and same-color distractors in the display and in both groups search became faster when the ratio moved towards the two extremes. The overall pattern of patients’ RT change with the change in the distractor ratio, suggests that, like controls, they benefit from the presence of a smaller distractor subset in the display. This suggests that they can flexibly deploy their attention to the smaller subset of distractors on each trial and that the distractor ratio effect remains robust among patients with SCZ. It is important to note that patients’ intact selectivity for the distractors in the smaller subset can be reliably inferred from their RTs because as revealed by Shen et al. (2000, 2003), there exists a very high correlation between RT and measures of saccadic selectivity for items belonging to the smaller distractor subset.

4. Discussion

The goal of the current study was to investigate whether impaired visual search performance among patients with SCZ can be accounted for by poor perceptual organization and impaired search selectivity. The distractor ratio paradigm was used as a task that requires both perceptual grouping and selectivity as means to guide visual search. Patients’ search time changed as a function of distractor ratio according to the typical pattern defined by the distractor ratio effect (i.e., the inverted V pattern). This indicates that patients, like controls, are most efficient at extreme distractor ratios and that they are able to group the search items based on their color or shape and can flexibly modulate their search according to the relative frequency of the two types of distractors in the display (i.e., shift their attention to the smaller subset of distractors in the display). Since the distractor ratio effect depends on the integrity of perceptual grouping and the ability to select the smaller subset of items in a search display, this study did not find evidence for the impairment of any of these two processes among SCZ patients. Patients’ search, however, was slowed to a greater degree when the relative frequency of distractors was one; that is, compared to controls, patients manifested steeper search slopes on the two sides of the inverted V. This is indicative of patients’ impaired visual search performance on this task. In fact, if perceptual grouping is intact, increasing the number of one type of distractor creates a situation that is similar to a display size increase. Therefore, this finding is consistent with previous findings of the exaggerated impact of display size on patients’ visual search performance. However, the reversal of patients’ search slopes when the number of one type of distractor exceeds half of the total search items suggests that patients are successfully switching their search to the other distractor type and the observed visual search impairment exists in spite of intact perceptual grouping and intact selectivity according to the distractor ratios.

These findings are consistent with previous findings of intact perceptual grouping among SCZ patients (Carr et al., 1998; Chey and Holzman, 1997; Rief, 1991). They are also consistent with the recent findings by Gold et al. (2006) of intact attentional selection for visual working memory encoding among SCZ patients. In a series of five experiments Gold et al. found that patients with SCZ were able to selectively attend to relevant information using perceptually salient peripheral cues as well as more abstract cues to guide their attention. Guidance of attention to the smaller subset of distractors is considered a form of bottom-up, perceptual guidance and, based on the results of the current study, is also intact among patients.

The current data are also consistent with physiological findings that indicate relatively preserved functioning of the ventral visual pathways in SCZ (e.g., Butler et al., 2001; Christensen and Bilder, 2000). The ventral stream...
projects to the inferotemporal cortex and is involved in the visual perception and discrimination of objects and patterns (Mishkin et al., 1983).

The inconsistency between the results of the current study and the studies that have found evidence for impaired perceptual grouping among SCZ patients (Place and Gilmore, 1980; Wells and Leventhal, 1984) may be due to the employment of different sets of stimuli. A critical factor in successful perceptual grouping is the discriminability of the different types of distractors from each other. The two types of distractors in the current study were highly salient and discriminable on both feature dimensions (i.e., red vs. green and X vs. O). The primary goal of this study was to investigate the influence of distractor ratio manipulations on the visual search performance of SCZ patients, and the results showed that this mechanism per se is intact among patients. However, under conditions of lower distractor discriminability, SCZ patients may demonstrate less efficient perceptual grouping compared to controls, and yield results that are more similar to the findings of Place and Gilmore (1980), and Wells and Leventhal (1984).

In contrast with findings of impaired cognitive control among SCZ patients (e.g., Cohen and Servan-Schreiber, 1992), patients in this study were able to modulate their search on a trial by trial basis, according to the relative frequency of the distractors, therefore demonstrating their ability to use the information present at each trial to adjust their search behaviour. The inconsistency between these results may be explained by a previous finding that modulation of visual search according to the ratio of distractors is predominantly governed by bottom-up factors (Shen et al., 2007). In fact, SCZ participants were also found to be as efficient as control participants in their set shifting ability on tasks with low memory demands (Meiran et al., 2000). Altogether these data indicate that patients with SCZ may be sufficiently flexible and successful in switching their behaviour according to the context, as long as there is low dependence on top-down cognitive processes.

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Contributors
This study was conducted in partial fulfillment of Ava Elahipanah’s M.Sc. thesis requirements. Accordingly she was responsible for all aspects of study design, data collection, statistical analysis, and manuscript preparation. The research was conducted under the supervision of Bruce Christensen who participated directly in all aspects of the study. Eyal Reingold served as a thesis committee member and an expert consultant with regards to task design, experimental methods and data interpretation. All authors contributed to and approved the final manuscript.

Conflict of interest
All authors declare that they have no conflict of interest.

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