Impaired Control of Visual Attention in Schizophrenia

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To investigate attentional impairment in schizophrenia, the authors examined the performance of 22 patients with schizophrenia and 16 healthy control subjects in 4 visual search tasks that varied in perceptual requirements and in the need for precise attentional control. The rate of search was slowed in the patients in all tasks. However, the degree of slowing was largest in tasks requiring precise attentional control and smallest in tasks that were perceptually difficult but required less attentional control. This pattern of results indicates that the primary impairment of attention in schizophrenia lies in the control of attention and not in the selection processes that operate once attention has been directed to an object.

Keywords: schizophrenia, visual search, control of attention, implementation of selection, executive control

Almost every description of cognitive deficits in schizophrenia highlights the importance of impairments in attention, beginning with the rich clinical descriptions of Kraepelin (1913/1919) and Bleuler (1911/1950). These clinical observations have been amply supported by an enormous experimental literature demonstrating a wide variety of behavioral impairments that are thought to reflect deficits in attention. However, the concept of an attention impairment has been used to describe very different patterns of behavioral performance. Consider, for example, these three examples: (a) Deficits in detecting targets from a series of visual stimuli in continuous performance tasks are typically described as resulting from a failure of sustained attention (Cornblatt & Keilp, 1994), (b) difficulties reporting cued stimuli when presented with dichotic stimuli are attributed to a failure of selective attention (Baribeau-Braun, Picton, & Gosselin, 1983; Lerner, Nachshon, & Carmon, 1977; Wahl, 1976), and (c) failures to shift to a new category in the Wisconsin Card Sorting Test are often discussed as representing a failure in the ability to shift attention (Goldberg, Weinberger, Berman, Pliskin, & Podd, 1987).

Note that in each of these examples, a deficit in attention is inferred from the failure of a different cognitive system: The continuous performance task involves visual perceptual and motor systems, dichotic listening involves auditory perception and memory, and the Wisconsin Card Sorting Test primarily involves conceptual representations and response selection. In each instance, it is difficult to disentangle the role of impairments within these cognitive systems from those that might represent the failure of attention to modulate the functioning of these systems. Thus, in light of the range of behavioral abnormalities attributed to some form of attentional dysfunction in the clinical research literature, it is not surprising that cumulative progress in identifying the critical cognitive elements and neural substrate implicated by abnormalities in attention has been slow.

In the present study, we sought to isolate more clearly the nature of attentional abnormalities in schizophrenia by focusing on two separable components of attention, namely the control of attention and the implementation of selection. The control of attention refers to the processes that determine what information should be attended and that are responsible for directing attention toward relevant sources of information. The implementation of selection refers to the processes that operate once attention has been directed to an object, allowing the attended object to receive preferential processing.

The Visual Search Paradigm

Over the past 30 years, substantial work by cognitive psychologists has yielded methods that can isolate specific varieties of attention more precisely than the commonly used clinical tasks can, and these methods therefore hold promise for isolating the nature of the attentional impairments in schizophrenia. In particular, visual search tasks have been used extensively to study various elements of attention, including the control of attention and the implementation of selection. In these tasks, an observer searches for a target object in an array containing many distractor
objects (see Figure 1), and the main dependent variable is the observer’s reaction time (RT). This is an excellent paradigm for studying attention because the degree of cognitive load can be systematically manipulated by varying the number of distractors and their similarity to the target.

Although there are conflicting theories of visual search, there is broad agreement that the distinctiveness of the search target relative to distractors is a major determinant of performance (see reviews by Duncan & Humphreys, 1989; Treisman, 1988; Wolfe, 1994). In cases where the target is defined by the presence of a single distinctive feature, visual search can be very rapid and efficient, with RT being relatively insensitive to the number of items in the array (the set size; see Figure 1A). Such highly efficient searches—sometimes called “pop-out” searches because the target appears to pop out from the distractors—are performed with minimal demands on spatial attention. That is, either the spatial focusing of attention is completely unnecessary for such tasks (Luck & Ford, 1998; Treisman, 1988) or attention is immediately directed to the target with little or no scanning of the distractors (Wolfe, 1994). In contrast, when the target is defined by a combination of features or is difficult to discriminate from distractors because of extensive feature overlap, RT increases steadily as the number of items in the search array increases, with very long RTs for large set sizes (see Figure 1B).

Visual search performance for a given condition is usually summarized in terms of the slope and intercept of the function relating RT to set size, which is called the search function. The slope of the search function represents the extent to which RT is slowed by the addition of each additional distractor item, and the intercept represents the duration of the processes that precede and follow the search process (e.g., preattentive sensory analysis, response selection). When the target pops out, the slope of the search function is near 0; that is, RT does not increase much as the set size increases. As the target becomes harder to find, the slope increases, reaching values between 25 and 75 ms per item for moderately difficult search tasks.

Steep search slopes are often thought to reflect a serial process in which attention is shifted from item to item until the target is found. However, steep slopes can also reflect a parallel process that becomes less efficient when multiple items are processed concurrently (Townsend, 1990). Here, we concentrate on tasks that are known to involve serial shifts of attention (Woodman & Luck, 1999, 2003). In such serial search tasks, observers must search half the items on average before finding the target. Consequently, the increased amount of time required to find the target when one item is added (i.e., the search slope) is really only half the amount of time required to search one item. Thus, the amount of time required to search one item—sometimes called the dwell time of attention—is equal to twice the search slope.

When attention is shifted serially, visual search involves at least four distinct subprocesses: (a) A representation of the target and task must be maintained in working memory; (b) a low-level sensory representation of the scene must be formed; (c) an attentional control mechanism must direct attention from one object to the next until the target is found while avoiding items that have already been searched; and (d) once attention is directed to an object, a selection mechanism must suppress competing information from nearby distractors so that the attended item can be compared with the target representation. Deficits in any of these subprocesses could lead to impaired search performance, but it is possible to design experiments in which specific components can be isolated.

![Figure 1. Example stimuli and search functions for an easy search task (A) and a more difficult search task (B).](image)

**Visual Search in Schizophrenia**

The literature examining variants of visual search in schizophrenia has yielded ambiguous results, and researchers in many of the studies have used methods that may not be optimal for isolating specific attentional processes. For example, deficits on the Span of Apprehension Test have often been documented, with patients diverging from controls when presented with larger search arrays (impairments with arrays of 8–12 items but intact performance with arrays of 1–3 items; see the review by Asarnow, Granholm, & Sherman, 1991). However, it is unclear if this represents a deficit in visual search because the display is typically shown for fewer than 100 ms, requiring subjects to search some form of iconic memory representation. Thus, a deficit in the formation or use of such a representation rather than a deficit in the search process may be responsible for the observed impairment in schizophrenia patients.

In a few studies, researchers have examined visual search performance in schizophrenia using methods closely resembling those in the basic science literature, but these studies have produced ambiguous evidence concerning attention deficits. One study found that patient slopes were steeper than control slopes for both
pop-out tasks and more difficult conjunction tasks (Carr, Dewis, & Lewin, 1998), and another reported that patient slopes did not differ significantly from those of controls in either task type, at least for target-present trials (Mori et al., 1996). However, the figures from Carr et al. and the slope values provided by Mori et al. reveal that patient slopes in the pop-out tasks were nearly twice those of controls. In contrast, patient slopes differed only modestly from control slopes (about 25% in Carr et al.) or not at all from control slopes (Mori et al., 1996) for target-present trials in the more demanding conjunction tasks (Carr et al., 1998; Mori et al., 1996). Paradoxically, it appears that patients may be proportionally more impaired in task conditions that are thought to involve a minimal role for spatial attention in healthy individuals, suggesting that patients may be searching inappropriately in pop-out tasks. These data raise the possibility that it is the control of attention that is the source of patient impairment, whereas the implementation of selection may be surprisingly intact. That is, patients may have difficulty determining which objects should be attended, but they may be able to process information efficiently once attention has been directed to an object.

A complicating factor in these prior studies is that the subjects—especially the patients—became less accurate as the set size increased. When a search task requires a response indicating whether a target is present or absent, observers typically search until they either find the target or give up, and they often give up before finding the target on target-present trials, especially at large set sizes (for an extensive discussion, see Chun & Wolfe, 1996). The slope of the search function is lower for observers who give up more quickly, and this is accompanied by an increase in the error rate at large set sizes. Thus, substantial slowing of the search process in patients may have been masked by speed-accuracy trade-offs in the studies of Carr et al. (1998) and Mori et al. (1996). To avoid this problem, it is possible to use a search task in which each array contains one of two possible targets and observers indicate which of the two targets is present. Because the observers know a target is present, they search until they find it, making very few errors. This makes it much easier to estimate the actual rate of search.

The Present Study

Our goal in the present study was to more precisely identify the attention-related processes that are impaired in schizophrenia, assessing performance in four search tasks that varied in perceptual difficulty and attentional control requirements (see Figure 2). Three of the tasks varied systematically in the amount of feature overlap between targets and distractors and thereby varied in the demand for fine perceptual processing. In these three tasks, the target was a square with a gap on the left or right side, and the subjects indicated which of these two targets was present in a given array.

In the feature task, the distractors were squares without a gap, so the target contained a feature that was absent in the distractors. This sort of task typically leads to very shallow search slopes.

In the large-gap task, the distractors had a gap on the top or bottom, making them identical to the targets except for the location of the gap; focused attention is known to be necessary for perceiving the spatial location of a feature within an object (Wolfe, 1994), and this particular task has been shown to involve the serial application of attention to determine whether each item is a target or a distractor (Woodman & Luck, 1999, 2003). Thus, this task typically leads to moderately steep search slopes.

The small-gap task was identical to the large-gap task except that the gaps were made smaller, making it even more difficult to determine whether a given item was a target or a distractor. This task should lead to even steeper search slopes.

If schizophrenia involves a deficit in perceiving an item once attention has been directed to it, then this should increase the amount of time that attention is focused on each item (i.e., the dwell time of attention), which in turn determines the slope of the

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<table>
<thead>
<tr>
<th>Feature Task</th>
<th>Large-Gap Task</th>
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<tbody>
<tr>
<td>Expected Search Slope: Shallow</td>
<td>Expected Search Slope: Medium</td>
</tr>
<tr>
<td>Perceptual Difficulty: Low</td>
<td>Perceptual Difficulty: High</td>
</tr>
<tr>
<td>Control Requirements: High</td>
<td>Control Requirements: Low</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Small-Gap Task</th>
<th>Comparison Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected Search Slope: Steep</td>
<td>Expected Search Slope: Very Steep</td>
</tr>
<tr>
<td>Perceptual Difficulty: High</td>
<td>Perceptual Difficulty: Medium</td>
</tr>
<tr>
<td>Control Requirements: Low</td>
<td>Control Requirements: High</td>
</tr>
</tbody>
</table>

Figure 2. Stimuli for the feature (A), large-gap (B), small-gap (C), and comparison (D) tasks. For each task, the figure lists the expected search slope in healthy subjects, the level of perceptual difficulty, and the need for precise attentional control. Set size varied between 4, 8, and 12 items. For the comparison task, the screen was divided into two rows of eight horizontal strips, with one column on each side of the vertical midline. These strips (shown here as dotted lines) were used to determine the locations of the stimuli but were not visible on the screen. Each strip was 4.4° × 1.0° and was centered 4.5° lateral to the vertical midline. The position for each of the items on the left of the screen was randomly selected within the strips, and then 9.0° (270 pixels) was added to the x-coordinate, leaving the y-coordinate the same so that each stimulus on the left had a matched stimulus on the right. The strips were divided into pairs: the top two strips, then the next two strips, and so on. The vertical distance between two strips of a pair (e.g., between Stips 1 and 2 or 3 and 4) was 0.3°, and the vertical distance between adjacent but unpaired strips (e.g., between Stips 2 and 3 or 4 and 5) was 1.3°. Set size was manipulated by varying the number of pairs of strips that contained items (e.g., a set size of 8 was created by putting items in two pairs of strips on one side and the corresponding two pairs on the other side). The total viewing area was 13.4° × 13.4°.
search function). The dwell time increases as the perceptual demands of the task increase, and increases in perceptual demands should therefore amplify the magnitude of the patient deficit. Thus, this sort of deficit would lead to progressively greater increases in search slopes for patients compared with controls as the search task is made more difficult. That is, search slopes should be elevated for the patient group relative to the control group, and the degree of elevation should be smallest in the feature task, larger in the large-gap task, and largest in the small-gap task.

In contrast, if schizophrenia does not disrupt the effectiveness of attention once it has been focused but instead influences the ability to control the allocation of attention, then the magnitude of the impairment will not depend directly on the difficulty of the target–nontarget discrimination. Instead, the magnitude of the impairment will be greatest under the conditions that require the greatest attentional control. Although the feature task is the easiest condition, it is actually the condition in which attentional control is most important.

Specifically, precise attentional control makes it possible to direct attention immediately toward the one item that has a gap, thus avoiding a time-consuming serial search of the array. If patients have a deficit in attentional control, they may often direct attention to nontarget items before attending to the target in the feature task, leading to a fairly steep search slope, whereas healthy individuals will do this very rarely, leading to a shallow search slope. Consequently, the slope of the search function should be substantially greater for patients than for control subjects in the feature task if patients have a deficit in attentional control. This contrasts with the prediction of very little difference between patient and control slopes for the feature task if patients have a deficit in the implementation of selection once attention has been focused.

In contrast to the feature task, the small- and large-gap tasks emphasize the implementation of selection rather than the control of attention. In these tasks, it is difficult to determine whether a given item is a target or a distractor until attention has been shifted to it, and a serial search is always required. In other words, attention shifts from item to item in a relatively random order in these tasks, so it is not necessary for control processes to direct attention to a specific item at a specific time. Instead, the main determinant of the search slope in these perceptually difficult tasks is the time required to determine whether a given item is a target once attention is focused on it, which depends on the difficulty of the target discrimination and the effectiveness of attention once it has been focused on a given item. Some attentional control may be necessary to avoid searching a given item multiple times, but attentional control will be less important in these tasks than in the feature task. Moreover, the need for attentional control is presumably no greater in the small-gap task than in the large-gap task, and a deficit in attentional control would therefore be expected to yield equivalent impairments in these tasks, even though the small-gap task is considerably more difficult.

In this experiment, we predicted that the magnitude of the patient impairment would be largest in the feature task, intermediate in the large-gap task, and smallest in the small-gap task. However, it is possible that this pattern could reflect some sort of scaling artifact and that patients will always show proportionally smaller deficits in more difficult tasks that produce steeper slopes. To demonstrate that this pattern is not a scaling artifact of this sort, we included a fourth search task that was very difficult but was predicted to yield large proportional impairments. The task was a modified version of the comparison search paradigm that was developed by Pomplun, Sichelschmidt, Wagner, Clermont, Rickheit, and Ritter (2001). In our version, each square on the left side of the display was paired with a square on the right side of the display (see Figure 2D). The nontarget pairs had gaps on different sides (e.g., one square had a left gap and the other had a right gap), and the target pair had gaps on the same side (e.g., both squares had gaps on the left side). The subjects indicated the side of the gap in the target pair. To perform this task, subjects must shift attention from one member of the pair to the other member of the pair so that the two items can be compared, which requires very precise control over attention. In contrast, standard search paradigms do not require observers to shift to a particular item at each moment. Thus, although the perceptual demands of the task were similar to those of the large-gap task, the need for precise shifts of attention in the comparison search task should lead to a greater level of patient impairment. Moreover, this task requires constant working memory updating, and this should also make the task difficult for patients given the extensive evidence for a working memory impairment in schizophrenia (Barch, 2004; Barch, Csernansky, Conturo, & Snyder, 2002; Nuechterlein et al., 2004). Thus, there are several reasons to expect patient performance to be highly impaired in this task, which will rule out the possibility that large proportional impairments can be found only in relatively easy search tasks.

Method

Subjects. Twenty-two patients on the schizophrenia spectrum meeting Diagnostic and Statistical Manual of Mental Disorders (4th ed.; DSM–IV; American Psychiatric Association, 1994) criteria for schizophrenia (4 paranoid and 17 undifferentiated type) or schizoaffective disorder1 (1) participated in the study, along with 16 healthy comparison subjects. Diagnosis was established for each patient using a best estimate approach combining information from past medical records, collateral informants (when available), and the results of a Structured Clinical Interview for DSM–IV diagnosis. The patients were clinically stable outpatients; 17 were receiving new generation antipsychotics, 4 were receiving traditional antipsychotics, and 1 was receiving both. All patients had been receiving the same medication, at the same dose, for at least 8 weeks prior to study participation.

The healthy controls were recruited from the community via newspaper advertisements and word of mouth and were screened using the complete Structured Clinical Interview for DSM–IV Axis I (First, Spitzer, Miriam, & Williams, 1997a) and the structured clinical interview for DSM–IV Axis II (First, Spitzer, Miriam, & Williams, 1997b). The healthy controls were free of a current or past history of major psychiatric illness and denied having a family history of psychotic disorders in first-degree relatives.

Demographic features are shown in Table 1. The two groups did not differ on demographic variables other than Wide Range Achievement Test (3rd edition; WRAT; Wilkinson, 1993) scores. The level of education attained by the father did not differ between groups, and we therefore

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1 Previous work has indicated that patients with schizoaffective disorder do not appear to differ from patients with schizophrenia on cognitive tasks such as spatial working memory, the Wisconsin Card Sorting Task (Gooding & Tallent, 2002), and context memory recall (Manschreck, Maher, Beaudette, & Redmond, 1997).
Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Patients</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
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<tr>
<td>Age</td>
<td>41.6</td>
<td>5.2</td>
</tr>
<tr>
<td>Education</td>
<td>12.6</td>
<td>1.9</td>
</tr>
<tr>
<td>Father’s education</td>
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<td>4.1</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Racial or ethnic group</td>
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<tr>
<td>Hispanic</td>
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<tr>
<td>Caucasian</td>
<td>15</td>
<td></td>
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<tr>
<td>Wide Range Achievement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test, 3rd ed.</td>
<td>85.9</td>
<td>14.6</td>
</tr>
</tbody>
</table>

a Data are unavailable for 2 patients and 2 healthy controls. b Data are unavailable for 2 healthy controls.

* p < .01.

assume that the WRAT differences were a result of the disease rather than true differences in demographic variables.

Tasks. The stimuli for each task are shown in Figure 2. They were presented on a video monitor at a distance of approximately 70 cm. The search arrays consisted of 0.47 × 0.47° outlined squares, drawn in white with a line thickness of 0.07° on a black background. In the large-gap and comparison conditions, one side was missing from each square, and one side was also missing from the target item in the feature condition. A gap of 0.07° was present on one side of each square in the small-gap task.

In the feature, large-gap, and small-gap tasks, each stimulus array contained 4, 8, or 12 items. To minimize density differences across set sizes in these tasks, we presented the items in clusters of 4, and we varied set size by manipulating whether one, two, or three quadrants of the display contained a cluster. The items in a cluster fell within a 4 × 4° region centered 3.5° from the horizontal and vertical midlines, and the items within a cluster were separated by at least 0.67° (center to center).

In the comparison search task, the display was divided into two invisible columns of eight regions (see Figure 2 for dimensions and placement details), and a white vertical line divided the display into two halves. The left column contained one, two, or three clusters of two items, each of which consisted of one item in each of two adjacent regions. The location of an item within a region was selected at random. Each item in the left column was paired with an item presented 9.0° to the right in the right column. The total set size was 4, 8, or 12 items (two, four, or six pairs).

In all four tasks, a target was present on every trial and contained a gap on the left or right side. In the feature condition, the distractors did not have a gap. In the large-gap and small-gap conditions, the distractors had a gap on the top or bottom. In the comparison condition, each item had a gap on the left or right side, and the target was defined as the one pair in which the gaps were both on the same side.

Subjects made a speeded response on a game controller for each stimulus array, responding with the left or right index finger depending on whether the target had a gap on the left or right side, respectively. The stimulus array remained on the screen until a response was made, and a 500-ms blank interval was interposed between the response and the onset of the next array.

Procedure. After providing written informed consent, subjects were presented with the four conditions—feature, large gap, small gap, and comparison—in random order. Prior to each condition, we provided instructions via a PowerPoint presentation, followed by one practice block. Additional practice blocks were administered if the participant asked for additional practice or if the participant’s accuracy in the practice block was below 80% correct. For each condition, there were 3 blocks containing 54 trials each, with a total testing duration of approximately 40 min. Short breaks were provided after every 10 trials. Each subject was presented with different randomly generated stimulus arrays.

Data analysis. We calculated the median RT for each condition and set size in each individual subject. These data were then analyzed using a 2 (group) × 4 (task) × 3 (set size) mixed-model analysis of variance (ANOVA). To provide a measure of the search rate, we also computed the least-squares best-fit slope of the function, relating median response time to set size for the four different tasks for each participant, and we performed a second set of ANOVAs on these slopes. The slope represents that increment in response time produced by adding each additional item to the search display, and it factors out the time required for presearch and postsearch processing (e.g., low-level sensory encoding, response selection). Because our predictions involved the proportional difference in slope and between controls and patients, we used the natural logarithm of each slope in our statistical analyses and fitted the model log(slope) = group + task + group × task. Geometric means for each group under each condition were calculated using the formula geometric M = exp[estimated M(log(slope))]. Taking the logarithm of a variable transforms proportional effects into additive effects, because log(slope/slope2) = log(slope1) − log(slope2). Consequently, if the slope for patients differs from the slope for control subjects by the same proportion across tasks, then this will lead to a main effect of group but no interaction between group and task. In contrast, if the differences in slope are not proportional to the slope, then an interaction between group and task will be observed. For comparisons of interest (e.g., feature task vs. comparison task in patients), we calculated the mean and standard error of the log-transformed differences and then obtained estimates of the mean slope ratio 95% confidence interval (CI) by the transformations ratio = exp[log(difference)], CI = exp[log(difference) + log(SE(differences))]. Ratios estimated in this manner are the ratios of the geometric means of the two slopes rather than the arithmetic means. It should also be noted that the untransformed slopes were somewhat skewed and the log transformation had the added benefit of normalizing the data and reducing the influence of outliers.

It is possible that the four search tasks may differ in psychometric sensitivity, thereby confounding the interpretation of our results. We therefore calculated the true score variance for the slopes of each task using the data of the control subjects (Chapman & Chapman, 1973, 1978; Miller, Chapman, Chapman, & Collins, 1995). This was done by multiplying the observed variance by the reliability for each task. There were 54 RT trials at each set size (4, 8, 12) for each task. One slope value was calculated for each trio of correct RTs (one correct RT at Set Sizes 4, 8, and 12) for each control subject, providing up to 54 slope values per task. Reliability was calculated for each task using Cronbach’s alpha. Observed variance was calculated for each task using the mean slopes for each control subject for each task.

Results

Subjects were highly accurate, with a mean of 98% correct or higher for each group in each task, indicating that the RTs were not confounded by speed-accuracy trade-offs. The means of the median RTs for each group are presented in Figure 3. Patient RTs were slower than control RTs across all set sizes in all tasks. RT slowed as set size increased in both groups, and RT was fastest in both groups for the feature task, followed by the large-gap task, the small-gap task, and the comparison task. The ANOVA on median RTs confirmed these impressions, with main effects of group, F(1, 36) = 13.1, p = .001; task, F(2, 55) = 69.1, p < .001; and set size, F(1, 45) = 149.0, p < .001. These main effects indicate that patients were slower overall, that RT varied as a function of task, and that RTs were slower with larger set sizes. These main effects
were accompanied by a significant Group × Task × Set Size interaction, $F(3, 108) = 7.9, p < .001$, indicating that the groups differed in the impact of set size across the tasks. Specifically, the impact of set size was greater for patients than for control subjects in all tasks, but the absolute magnitude of this difference varied across tasks.

To simplify this three-way interaction, we summarized the data from each combination of group and task as a search slope, and the mean slope values are shown in Figure 4. The validity of this approach was supported by the fact that the linear trend for the mean of the medians accounted for at least 99% of the variance for each combination of group and task. As can be seen in Figure 4,

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**Figure 3.** Mean of the median reaction time (RT) data for the patients with schizophrenia (triangles) and controls (squares) with linear trend lines fit to the data for the feature, large-gap, small-gap, and comparison tasks. Error bars represent within-subjects confidence intervals (as defined by Loftus & Masson, 1994).

**Figure 4.** Mean slope values for the patients (black) and control subjects (white) for the feature, large-gap, small-gap, and comparison tasks. The numbers above the figures represent the percentage of difference between groups ($100 \times \frac{\text{mean patient slope} - \text{mean control slope}}{\text{mean control slope}}$). The numbers below the figures indicate the exact values shown by the individual bars. Error bars represent within-subjects confidence intervals (as defined by Loftus & Masson, 1994).
control group slopes were less than 15 ms/item in the feature task and rose across conditions to almost 200 ms/item in the comparison search task. The slopes were greater for patients than for control subjects in all four tasks. This difference was significant in the feature, large-gap, and comparison tasks (all \( p < .05 \)), but it was not statistically significant in the small-gap task, \( t(36) = 1.5, p = .12 \).

The absolute difference in slope between patients and control subjects tended to grow as the slopes became greater, except the difference was approximately equal for the small-gap and large-gap conditions. In addition, there were wide variations in the proportional slope difference between patients and control subjects across the four search tasks. Figure 4 makes this clear by also indicating the percentage difference in slope between the patients and control subjects for each task. The extent of slowing is dramatic: The patient slope in the feature condition was more than twice that of the control slope, and patient slopes were elevated by as much as 172 ms/item greater than mean control slopes, and overall patient slopes were substantially greater than control slopes in both absolute and proportional terms. In absolute terms, mean patient slopes were as much as 2.4 s greater for the patient group than for the controls. The pattern of slope differences was not an artifact of psychometric discriminating power. The feature task contained the smallest true score variance (35.4) followed by the large-gap task (717.2), the small-gap task (2,749.9), and the comparison task (2,924.6). If the pattern of effects was driven by the psychometric power of the tasks to show differences, we would predict the patients would differ from the controls most on the comparison task and least in the feature task. Because this was not the case, we can conclude that the patient deficits, especially those found in the feature task, are not due to differences in the intrinsic psychometric sensitivity of the tasks.

**Discussion**

In this study, we used visual search tasks to isolate a specific variety of attention, one that is responsible for shifting the focus of perceptual processing from item to item while observers search for a target (Woodman & Luck, 1999, 2003). Researchers in previous studies have also examined visual search performance in schizophrenia, but they generally found little or no increase in patient slopes compared with control slopes on target-present trials, and the differences did not vary in a consistent manner between easy pop-out tasks and more difficult conjunction tasks (Carr et al., 1998; Mori et al., 1996). The methods used in the present study, however, were designed to be more sensitive than those used in previous studies. In particular, the present study examined a wider range of difficulty levels, and the presence of a target on every trial minimized speed-accuracy trade-offs. The use of these optimized methods led to two major findings.

**Major findings.** The first major finding was that patient slopes were substantially greater than control slopes in both absolute and proportional terms. In absolute terms, mean patient slopes were as much as 172 ms/item greater than mean control slopes, and overall RTs were as much as 2.4 s greater for the patient group than for the

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2 We compared the slope values from the first half of each task with the slope values from the second half of each task in a repeated-measures ANOVA. In each task, the Time (first half and second half) \( \times \) Group (patients and controls) interaction was not significant (\( p > .3 \)). We believe these results support the argument that there were no differential fatigue effects in the patients.
control group. In proportional terms, mean patient slopes were as much as 109% greater than mean control slopes, and overall RTs were as much as 88% greater for the patient group than for the control group. These are extremely large deficits for a set of simple laboratory tasks, and it is therefore reasonable to suppose that the underlying cognitive impairment may substantially impact performance on a variety of cognitive measures as well as functioning in everyday life. For example, patients with schizophrenia demonstrate remarkable slowing on measures of visual-motor processing speed such as the digit symbol and letter cancellation tasks (Agarwal, Kalra, Natu, Dadhich, & Deswal, 2002; Mirsky, Ingraham, & Kugelmass, 1995; Pandey & Mishra, 2002; van Hoof, Jogems-Kosterman, Sabbe, Zitman, & Hulstijn, 1998). These tasks impose a trivial challenge to higher order cognitive systems but impose a clear demand for rapid and efficient visual search. The search deficit observed in the present study may play a large role in these previously described impairments. In addition, the present results may indicate that patients with schizophrenia are meaningfully impaired in real-world tasks that involve shifting attention in cluttered scenes. Tasks as mundane as scanning the TV listings for a preferred program or finding the right variety of soup on a shelf may require significantly more time and effort for patients than for people without schizophrenia.

The second major finding was that the proportional size of the slope difference varied substantially across tasks. Specifically, the proportional difference in slopes was largest in the feature search task, which had the smallest absolute slope difference. However, large proportional slope differences are not a necessary consequence of small overall slopes, because the comparison search task yielded a large proportional slope difference even though it was the condition with the steepest slopes.

Implications. Together, these findings lead to the following three conclusions. First, schizophrenia involves a substantial deficit in a specific and well-studied variety of attention. Although this conclusion is consistent with decades of research that has been interpreted as evidence for impaired attention in schizophrenia, the specific attentional mechanisms have remained poorly specified in the literature, and previous studies have not provided clear evidence of a deficit in the operation of attention in visual perception. Specifically, previous studies of visual search did not find robust increases in patient slopes (Carr et al., 1998; Mori et al., 1996), and studies using spatial cues to direct visual attention have been inconsistent in showing deficits of visual attention in patients with schizophrenia (Bustillo et al., 1997; Carter, Robertson, Chaderjian, Celaya, & Nordahl, 1992; Fuentes & Santiago, 1999; Gold et al., 1992; Liotti, Dazzi, & Umlita, 1993; Moran, Thaker, Smith, Cassidy, & Layne-Gedge, 1992; Nestor et al., 1992; Posner, Early, Reiman, Pardo, & Dhawan, 1988; Strauss, Novakovic, Tien, Bylsma, & Pearson, 1991). Thus, the robust and specific deficits observed here represent an advance in understanding exactly what varieties of attention are impaired in schizophrenia.

The second conclusion is that the observed deficit does not reflect some sort of generalized slowing. If schizophrenia produced a slowing of all processes involved in performing visual search, then the degree of impairment should have been proportional to the difficulty of each task, leading to the same percentage increase in slope across conditions. The fact that the proportional difference between patient slopes and control slopes was more than three times larger in the feature task than in the small-gap task provides strong evidence against an account based on generalized slowing. The results argue instead for a more specific impairment in attention.

The third conclusion is that this specific impairment involves the control of attention rather than the implementation of selection. That is, there appears to be an impairment in the processes that determine when and where attention is allocated rather than an impairment in the processes that operate to identify an item once attention is focused on it. If patients are impaired at identifying an object once it is attended, then performance should be most impaired under conditions that stress the identification of objects. However, we observed the smallest proportional impairment in the small-gap condition, in which object identification was most difficult. Moreover, the absolute impairment in the small-gap condition was approximately the same as the absolute impairment in the large-gap condition, even though the small-gap condition involved a substantially more difficult object identification task (as evidenced by the finding that the small-gap slope was more than twice as large as the large-gap slope in the control subjects). In addition, the largest proportional impairment was observed in the feature task, in which the target detection task was easiest. These findings provide no evidence for a deficit in identifying an object once attention has been shifted to it.

The results are instead consistent with a deficit in attentional control. Healthy individuals can detect pop-out targets rapidly, and under most conditions this involves only one shift of attention. If attention shifts to the wrong item just once or twice per trial when the set size is large, this will lead to a large proportional increase in the slope. In more difficult search tasks, however, the location of the target cannot be determined until attention has been shifted to it, and most shifts of attention will be to a nontarget item. As a result, it does not matter as much whether attention shifts to a particular item at a particular moment. Indeed, shifting attention to an unintended item may sometimes cause attention to shift to the target sooner rather than later. Thus, occasional incorrect shifts of attention will have a smaller proportional impact on the slope for tasks that are perceptually difficult. An impairment in attentional control can therefore account for the pattern of differences observed between patients and control subjects across tasks.

The nature of attentional control. To understand what it means for attentional control to be impaired, it is useful to consider the conceptualization of attentional control developed by Logan and Gordon (2001). They define an executive control system as a system that sets the parameters that determine the operation of another system. In the case of attentional control, they hypothesized an executive system that can translate a verbal task description (e.g., “respond with the left hand if you see a target with a left gap”) into a set of parameters that controls the operation of an attentional selection system. These parameters represent factors such as the features that define the target for the task (e.g., a left or right gap). If these parameters are not set correctly within the attentional selection system, then search performance should be impaired exactly in the manner observed here. The executive system is presumably localized in prefrontal cortex, whereas the attentional selection system is presumably localized in posterior areas, including the posterior parietal lobe and modality-specific sensory cortices.

According to this conceptualization, attentional control will be impaired if the executive control system cannot accurately form
and maintain an accurate representation of the task. This could be a result of impairments in working memory, because Logan (2004) has shown that working memory is used by executive systems to maintain and use information about task definitions. Thus, the present results can be explained by postulating that patients with schizophrenia have difficulty maintaining or using an accurate representation of a visual search task in working memory. This accords with the proposal of Cohen and his collaborators that deficits in the representation of context in working memory can explain impaired performance in attention tasks (see, e.g., Cohen, Barch, Carter, & Servan-Schreiber, 1999).

Attentional control also relies on lower-level systems in the posterior parietal lobe that are involved in shifting attention from location to location (Corbetta, Shulman, Miezin, & Petersen, 1995; Robertson, Treisman, Friedman-Hill, & Grabowecky, 1997; Steinmetz & Constantini, 1995). That is, even if the parameters that control the attentional selection system have been set properly by prefrontal executive systems, the parietal component of the attentional selection system may be unable to accurately plan and execute shifts of attention. For example, theories of visual attention have postulated that the brain maintains a map of locations that represents preattentive information about the likelihood that a given location contains a target, and this map is used to control the order in which items are searched (Koch & Ullman, 1985; Treisman & Sato, 1990; Wolfe, 1994). If this map was noisier in patients than in control subjects, then this could explain the pattern of deficits observed in the present study. Given the overwhelming evidence for prefrontal deficits in schizophrenia, this possibility seems less likely than a higher level deficit in prefrontal executive systems. Moreover, we have recently shown that patients with schizophrenia can switch attention rapidly and accurately when bottom-up cues provide a clear indication of which location is to be attended, minimizing the need for prefrontal executive control (Luck et al., 2006). However, additional research is necessary to definitively distinguish between a high-level deficit in executive control systems and a lower level deficit in an attention-shifting mechanism.

References


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