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Hyperfocusing in Schizophrenia: Evidence from Interactions Between Working Memory and Eye Movements

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Abstract

Recent research suggests that processing resources are focused more narrowly but more intensely in people with schizophrenia (PSZ) than in healthy control subjects (HCS), possibly reflecting local cortical circuit abnormalities. This *hyperfocusing* hypothesis leads to the counterintuitive prediction that, although PSZ cannot store as much information in working memory as HCS, the working memory representations that are present in PSZ may be more intense than those in HCS. To test this hypothesis, we used a task in which participants make a saccadic eye movement to a peripheral target and avoid a parafoveal nontarget while they are holding a color in working memory. Previous research with this task has shown that the parafoveal nontarget is more distracting when it matches the color being held in working memory. This effect should be enhanced in PSZ if their working memory representations are more intense. Consistent with this prediction, we found that the effect of a match between the distractor color and the memory color was larger in PSZ than in HCS. We also observed evidence that PSZ hyperfocused spatially on the region surrounding the fixation point. These results provide further evidence that some aspects of cognitive dysfunction in schizophrenia may be a result of a narrower and more intense focusing of processing resources.

Keywords

Schizophrenia; working memory; hyperfocusing; saccadic eye movements; distraction

This study tests a recent hypothesis about the nature of impaired attention and working memory (WM) in schizophrenia (Hahn, Hollingworth, Robinson, Kaiser, Leonard, Beck, Kappenman, Luck, & Gold, 2012; Hahn, Robinson, Harvey, Kaiser, Leonard, Luck, & Gold, 2011; Leonard, Kaiser, Robinson, Kappenman, Hahn, Gold, & Luck, 2012). The essence of this hypothesis is that processing resources are focused more intensely¹ but more narrowly

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in PSZ than in healthy control subjects (HCS). In other words, PSZ focus unusually strongly on some sources of information to the exclusion of others. We call this the *hyperfocusing* hypothesis. It is intended to explain both attentional abnormalities and reduced WM capacity in PSZ.

Although the idea that PSZ have impaired attention is common (see review by Luck & Gold, 2008), studies using precise measures of selective attention have not found much evidence that PSZ have a reduced ability to focus on relevant information and exclude irrelevant information. In the spatial cuing paradigm, for example, a cue indicates that attention should be directed to a specific location. Healthy individuals are faster and more accurate when the target is presented at the cued location (*valid* trials) than when the target is presented at an uncued location (*invalid* trials) (Posner, 1980). If PSZ had an impaired ability to focus attention, then they should exhibit a smaller difference in performance between valid and invalid trials, but this validity effect is generally unimpaired in PSZ (Gold, Fuller, Robinson, McMahon, Braun, & Luck, 2006; Gold, Hahn, Strauss, & Waltz, 2009; Hahn et al., 2012). Moreover, a widely replicated finding is that the performance benefit of valid cues relative to spatially non-predictive cues is often greater in PSZ than in HCS (Bustillo, Thaker, Buchanan, Moran, Kirkpatrick, & Carpenter, 1997; Gold, Randolph, Coppola, Carpenter, Goldberg, & Weinberger, 1992; Hahn et al., 2012; Liotti, Dazzi, & Umiltà, 1993; Sapir, Henik, Dobrusin, & Hochman, 2001; Spencer, Nestor, Valdman, Niznikiewicz, Shenton, & McCarley, 2011). This finding of enhanced cue validity suggests that PSZ hyperfocus on the cued location on valid trials or fail to distribute attention effectively on neutral trials.

In WM studies, PSZ reliably exhibit reduced storage capacity (Lee & Park, 2005; Piskulic, Olver, Norman, & Maruff, 2007). There are many possible explanations for this impairment, but a recent event-related potential (ERP) study provided evidence that the deficit arises because PSZ tend to devote more processing resources to a smaller number of items (Leonard et al., 2012). Participants in this study were instructed to encode the items on one side of the display and to ignore the other side. This made it possible to record the *contralateral delay activity* (CDA), an ERP component that reflects the WM resources devoted to the cued side (Vogel & Machizawa, 2004; Vogel, McCollough, & Machizawa, 2005). When the cued side contained only one item, PSZ exhibited a larger CDA than did HCS, indicating that PSZ allocated more resources to the cued side than did HCS (hyperfocusing on the cued side). In contrast, PSZ exhibited reduced CDA amplitude (and impaired behavioral performance) when asked to store 3 or 5 items in WM. This would be expected if HCS could easily divide their resources among multiple items, whereas PSZ focused narrowly on only a small subset of the to-be-remembered items. In addition, the larger CDA in PSZ for 1-item arrays was found even for subgroups of PSZ and HCS who were matched for overall WM capacity, showing that it was not an artifact of differences in capacity.

¹We use the term *intensity* to describe the level of activation of a representation (which may be related to the firing rate of the neurons that code the representation). We have avoided the term *strength*, because greater strength might imply a greater resistance to distraction, whereas greater intensity (a higher activation level) does not necessarily mean that the representation is more robust. However, greater intensity of one representation would presumably increase the ability of this representation to compete or interfere with other concurrent representations.

Evidence of hyperfocusing has also been observed in experiments that combined attentional manipulations with WM encoding. In one series of experiments (Gold et al., 2006), participants were cued to a subset of the items in an array; memory for the cued items was tested on most trials (valid trials), but memory for the uncued items was tested on a subset of trials (invalid trials). When the arrays contained two cued items and two uncued items, PSZ were better than HCS at keeping the uncued items out of WM. In a related study (Hahn et al., 2012), participants stored a sequence of objects in WM and were tested at the end of the sequence. On some trials, one object in the sequence was accompanied by a cue tone, and subjects were instructed to focus on this object because it was very likely to be tested. Both PSZ and HCS were able to selectively store this object in WM. On other trials, a second object was also accompanied by a cue tone, indicating that the first cued object was now the least likely to be tested and this newly cued object was now the most likely to be tested. PSZ were significantly more successful than HCS at “flushing” the first cued object from WM. This is exactly what would be expected if PSZ hyperfocused on the currently most relevant item, causing other items to be excluded from WM.

Note that we would not expect to see evidence of more intense focusing in PSZ than in HCS in tasks where the optimal strategy is to focus attention intensely. HCS can presumably focus attention just as well as PSZ when the task requires it. However, many paradigms (and real-life situations) require allocating just the right amount of attention to one source of information so that resources remain for processing other sources. In cuing paradigms, for example, subjects are sometimes tested on the uncued items, and intense focusing on the cued item may therefore be suboptimal. This is the sort of situation in which we would predict that PSZ would exhibit more intense focusing than HCS. As another example, consider the attentional blink paradigm, in which subjects see a rapid stream of items and must identify two targets within the stream. Focusing attention onto the first target leads to a failure to detect the second target (an attentional blink), and studies of healthy young adults have found that greater focusing on the first target leads to a larger or longer-lasting attentional blink (Maclean & Arnell, 2011; Shapiro, Schmitz, Martens, Hommel, & Schnitzler, 2006). Similarly, PSZ exhibit an exaggerated attentional blink (Cheung, Chen, Chen, Woo, & Yee, 2002; Mathis, Wynn, Breitmeyer, Nuechterlein, & Green, 2011; Wynn, Breitmeyer, Nuechterlein, & Green, 2006), consistent with the idea that they are hyperfocusing on the first target and therefore failing to detect the second target. It should be noted that most of the research on this topic has been performed with chronic, medicated, clinically stable outpatients, and we do not yet know if the proposed hyperfocusing pattern is also present in other subpopulations of PSZ.

The hyperfocusing hypothesis leads to a counterintuitive prediction: Although PSZ are less likely to hold a given object in WM because of encoding failures (Lee & Park, 2005), the WM representations of PSZ will be more intense than those of HCS when a WM representation is actually present. This prediction follows directly from the finding that the ERP signature of WM maintenance—the CDA—is significantly larger in PSZ than in HCS when a single item is being stored in WM (Leonard et al., 2012). Testing this prediction is complicated by the fact that many cognitive processes are impaired in PSZ, such as global lapses of attention (Barch, Carter, Dakin, Gold, Luck, MacDonald III, Ragland, Silverstein, & Strauss, 2012), and this may artifactually create the appearance of weaker WM

representations. Thus, PSZ might exhibit a lower likelihood of maintaining an object in WM and yet still have more intense WM representations for the subset of trials on which the object is present in WM. To test the strength of the WM representations, it is therefore necessary to have a means of measuring the strength selectively for the trials on which a representation is present.

To measure the strength of WM representations in PSZ and HCS, the present study used a paradigm that was recently developed to examine how WM influences eye movements (Hollingworth, Matsukura, & Luck, 2013b). In the eye movement portion of this task (see Figure 1), participants were instructed to make a saccade to a target circle that appeared to the left or right of fixation, ignoring a distractor circle that sometimes appeared above or below fixation. This eye movement task occurred during the retention interval of a WM task. Specifically, participants encoded a colored square into WM at the beginning of each trial, and they performed the eye movement task while this item was held in working memory. Memory for the size of the square was then tested at the end of the trial. The distractor in the eye movement task sometimes matched the color of the square being held in WM, which makes the distractor more potent (Hollingworth et al., 2013b). If WM representations are more intense in PSZ than in HCS, then this should increase the amount of interference produced by a distractor that matches the contents of WM. Moreover, because WM is tested on every trial in this paradigm, it is possible to exclude trials on which the participant failed to store the object in memory. Thus, this task makes it possible to determine whether WM representations are more intense in PSZ than in HCS (when the representations are present).

Note that it is also important to consider the possibility that greater distractor interference might instead reflect a general impairment in the ability to suppress distraction. However, as will be described in detail in the Discussion, PSZ do not typically exhibit a general, task-independent increase in distractibility. That is, PSZ may exhibit greater distraction than HCS in some paradigms, but this is not a result of a generalized deficit in the ability to suppress distracting stimuli.

The present task also provides two indirect means of testing the hyperfocusing hypothesis. Both are based on the idea that some amount of attention must ordinarily be devoted to the fixation point if the task requires fixation at the beginning of the trial. Studies in nonhuman primates have shown that attentive fixation of a central spot will lead to decreased saccadic amplitudes (hypometric saccades), which appears to reflect an averaging of the fixation vector and the saccade target vector (Pare, Crommelinck, & Guitton, 1994; Schiller & Sandell, 1983). If PSZ hyperfocus on the fixation point, then this should make fixation stronger, leading to hypometric saccades when gaze is shifted toward a peripheral target. Consistent with this hypothesis, we recently found that PSZ exhibit a greater frequency of hypometric saccades than HCS in a simple prosaccade task (Leonard, Robinson, Kaiser, Hahn, McClenon, Harvey, Luck, & Gold, 2013) (see also Everling, Krappmann, Preuss, Brand, & Flohr, 1996; Hutton, Cuthbert, Crawford, Kennard, Barnes, & Joyce, 2001). If this result can be replicated in the present study, it would be consistent with the hypothesis the PSZ hyperfocus on fixation.

In addition, if the hyperfocusing extends to the region immediately surrounding the fixation point, then this may cause the distractor in the present study to be more potent in PSZ than in HCS. That is, the distractor in this paradigm is very close to the fixation point, and if PSZ devote more resources to this region than do HCS, then the distractor should produce greater interference in PSZ than in HCS. It should be noted, however, that this last prediction does not provide a strong test of the hyperfocusing hypothesis, because the paradigm does not parametrically vary the eccentricity of the distractor. The strongest test comes from determining whether the distractor produces disproportionately more interference when it matches WM.

Method

Participants

The participants consisted of 33 people meeting the criteria for schizophrenia (N=26; 9 paranoid, 1 disorganized, 3 residual, 1 catatonic, 12 undifferentiated) or schizoaffective disorder (N=7) and 34 HCS.

For PSZ, diagnosis was based on the standard operational criteria in the Diagnostic and Statistical Manual of the American Psychiatric Association IV (DSM IV) and was established using a best estimate approach, combining material from past medical records, collateral informants (when available), and the results of the Structured Clinical Interview for DSM IV-TR Axis I Disorders. Final diagnosis was reached at a consensus conference involving clinical staff chaired by J.M.G. The PSZ were clinically stable outpatients who had been receiving the same medications, at the same dose, for at least 4 weeks prior to study participation. Five PSZ were receiving typical antipsychotics, 27 were receiving atypical antipsychotics, and 1 was receiving both; 27 PSZ were additionally prescribed antidepressants, 11 mood stabilizers, 17 anxiolytics, 3 sleep aids (2 zolpidem, 1 diphenhydramine), and one modafinil for excessive sleepiness.

HCS were recruited by random digit dialing in the greater Baltimore metropolitan area. They had no current diagnosis of any Axis I disorder or Axis II schizophrenia spectrum disorder, and they self-reported no lifetime history of psychosis and no family history of psychotic disorders in first-degree relatives. They were screened using the complete Structured Clinical Interview for DSM-IV Axis I Disorders (First, Spitzer, Gibbon, & Williams, 1997) and Axis II Personality Disorders (Pfohl, Blum, & Zimmerman, 1995).

Several neuropsychological and symptom measures were obtained, including the Wechsler Abbreviated Scale of Intelligence (WASI IQ -- Wechsler, 1999), the Scale for the Assessment of Negative Symptoms (SANS -- Andreasen, 1984), and the Brief Psychiatric Rating Scale (BPRS -- Overall & Gorham, 1962). Demographic information, neuropsychological test scores, and psychiatric ratings are provided in Table 1. No significant differences were found between groups in age [$t(65) = 0.35, p > 0.7$], race [Chi-square, $p > 0.5$], gender [Chi-square, $p > 0.8$], or parental education [$t(64) = 0.52, p > 0.6$]. The PSZ had completed fewer years of education than the HCS [$t(65) = 3.47, p < 0.001$], which presumably reflects the effect of schizophrenia on educational attainment.

The participants in both groups were free of other medical or neurologic disorders that might interfere with test performance, including substance abuse or dependence within the last 12 months. The protocol was approved by the Institutional Review Board at the University of Maryland School of Medicine, and all participants gave informed consent before taking part in the study.

Stimuli and Procedure

Stimuli were presented on a 17" cathode ray tube monitor with a 60 Hz refresh rate, viewed at a 70 cm distance. All stimuli appeared against a gray background with a constant white central fixation cross subtending 0.3° . A chin/forehead rest was used to stabilize head position. An Eyelink 1000 tabletop eye tracker (SR Research Ltd., Mississauga, Ontario) recorded eye movements from the right eye at 1000 Hz.

In the main condition of this experiment, participants performed a WM task, and they also performed an eye movement task during the delay interval of the WM task on a majority of trials (see Figure 1).

The WM task began with the presentation of a *sample* square that covered the fixation cross for 300 ms. This square was $1.29\text{--}2.43^\circ$ wide, and the subject's task was to remember the size of the square to perform a comparison task at the end of the trial. The color of the square was randomly selected on each trial from the set {red, green, blue}. The color was task-irrelevant, but storing one feature of an object in WM ordinarily causes the other features to be automatically stored as well (Hollingworth et al., 2013b; Hyun, Woodman, Vogel, Hollingworth, & Luck, 2009). By making the color task-irrelevant, we could avoid inducing the strategic use of the color of the target or distractor from the eye movement task.

When the WM task was performed without the interposed saccade task, the sample square was followed after a delay by the presentation of two *comparison* squares, one centered 2.86° to the left of fixation and the other centered 2.86° to the right of fixation. One randomly selected square exactly matched the size of the sample square, and the other was either larger or smaller by 0.43° . Both comparison squares were always presented in the same color as the sample square to avoid any incongruity effects. Participants were instructed to make an unspeeded button-press response with the left or right index finger to indicate whether the left or right comparison square, respectively, matched the size of the sample square. The comparison squares disappeared when the response was made, initiating the next trial.

On 75% of trials, the saccade task was interposed during the delay interval of the memory task. On these trials, a target circle ($.86^\circ$ diameter) was presented 700 ms after the offset of the sample square. The target was always presented on the horizontal meridian, $4.38\text{--}6.14^\circ$ to the left or $4.38\text{--}6.14^\circ$ to the right of the fixation cross (with equal probability). On 50% of trials that contained a saccade target, the target was accompanied by a simultaneous distractor circle (0.94° diameter). The distractor was always presented on the vertical meridian, either 2.14° above or 2.14° below the fixation point (with equal probability). The target (and distractor, when present) was visible until the subject fixated within 0.57° of the target center for 17 ms, followed by a 400-ms delay and then the comparison squares for the

memory task. Participants were instructed to make a speeded saccade to the saccade target as soon as it appeared, and they also made the unspeeded memory comparison judgment when the comparison squares appeared. When a saccade target was presented, the overall delay between sample offset and comparison onset was 1100 ms plus the time required to fixate the target. When a saccade target was not presented, the delay was yoked to the observed delay on the most recent trial on which a saccade target had been presented. Each trial ended with a 500-ms blank intertrial interval, and the next trial was initiated as soon as gaze remained within 0.86° of the fixation point for 300 ms.

Trials were excluded from all analyses if gaze was not within 1° of the fixation point at the time of target onset. This led to the exclusion of 23.44% of trials in PSZ and 26.75% of trials in HCS, which was not a significant difference, $t(65) = 1.33, p = .19$. We tested 2 blocks of 112 trials, leading to a total of 32 trials without a saccade target, 96 trials on which the saccade target appeared without a simultaneous distractor, and 96 trials on which the saccade target and a simultaneous distractor were present.

When the saccade target was presented alone, it matched the color of the sample square on 50% of trials and was one of the other colors, selected at random, on the remaining 50% of trials. When the saccade target was presented with a simultaneous distractor, the target matched the color of the sample square on 1/3 of trials, the distractor matched the color of the sample square on a different 1/3 of trials, and neither item matched the color of the sample square on the remaining 1/3 of trials. These manipulations let us determine: (a) whether saccade performance was impaired when a distractor was present compared to when no distractor was present; (b) whether saccade performance was impaired when the distractor matched the color being held in WM compared to when the distractor did not match this color; and (c) whether saccade performance was improved when the target matched the color being held in WM compared to when it did not match (both in the presence and in the absence of distractor item). Note that all of these trial types were presented in an unpredictable order.

Trials with and without the saccade task were unpredictably mixed, so memory performance on trials without a saccade target could be used to estimate the quality of the memory of the sample square on trials that contained a saccade target. This made it possible to determine whether PSZ had a poorer working memory representation than HCS of the sample square. It is possible that PSZ devote less effort than HCS to remembering the sample square in an attempt to avoid impaired saccade performance. To assess this possibility, we included a block of 32 trials in which saccade targets never appeared (and participants knew this). These trials were used to assess memory abilities in the absence of a second task. The memory-only block was always tested last.

Data Analysis

For the memory task, the dependent variable was the percentage of trials on which the subject correctly selected the comparison square that matched the size of the sample square.

For the saccade task, we defined three main areas of interest (AOIs): 1) a $2 \times 2^\circ$ square *fixation region*, centered on the fixation point; 2) a rectangular *target region* that was 2°

high and extended horizontally from the edge of the fixation region to 1° past the location of the target (which varied in eccentricity from trial to trial); 3) a square *distractor region* that was 2° wide and extended vertically from the fixation region to 1° past the location of the distractor. As shown in Figure 2, we also defined an *opposite-distractor region* that was the mirror image of the distractor region on distractor-present trials. This region was used to assess the possibility that fixations in the distractor region were actually inaccurate refixations of the fixation point. As illustrated in Figure 2, less than 0.01% of initial saccades landed in this region, so this region was not considered further.

Trials on which the memory task was performed incorrectly were excluded from all eye movement analyses. This reflects our goal of determining whether working memory representations in PSZ, *when present*, are more intense or have a bigger impact on behavior than working memory representations in HCS. Trials were also rejected if the first saccade occurred outside the typical time range of target-directed saccades (100–400 ms). Less than 5% of trials were rejected for this reason.

A combined velocity ($> 30^\circ/\text{s}$), acceleration ($> 9500^\circ/\text{s}^2$), and landing position (outside the fixation region) threshold was used to define saccades. However, our main measure of timing was the amount of time required for gaze to reach a given area of interest. This allowed us to avoid treating small re-fixation saccades (which were quite common) as target-directed saccades.

Results

Memory accuracy

Memory accuracy was analyzed to ensure that any differences between groups in saccade performance did not reflect tradeoffs between the memory task and the saccade task.

Figure 3 shows performance on the size memory task for PSZ and HCS on three types of trials: trials on which a saccade target was presented during the delay interval; trials on which a saccade target was likely to occur but was not presented; and trials from the memory-only blocks. Memory accuracy was not influenced by whether the target was accompanied by a distractor, so the analyses were collapsed across distractor-present and distractor-absent trials. Size memory accuracy was slightly poorer overall for PSZ than for HCS on all three trial types. Performance in both groups was best in the memory-only block and poorest when the saccade target was present in the mixed blocks. These data were analyzed in an ANOVA with factors of group and trial type. The poorer performance of PSZ led to a significant main effect of group [$F(1, 65) = 4.052, p = .048$], and the differences across trial types were also significant [$F(2, 130) = 18.374, p < .001$]. However, the interaction was not significant [$F(2, 130) = 2.192, p = .116$]. The modest impairment in PSZ accords with many previous studies of impaired WM in schizophrenia (see review by Lee & Park, 2005), and the small magnitude of the differences in performance across conditions in both PSZ and HCS indicates that participants in both groups did a good job of maintaining

²IQ scores were unavailable for one PSZ and one HCS. SANS scores were unavailable for three patients. BPRS scores were unavailable for two patients.

the WM representations during the eye movement task. The lack of interaction between trial type and group indicates that any tradeoffs between the memory task and the saccade task were similar for the two groups.

Effect of Distractor Presence on Eye Movements

Our first analysis of saccade performance examined the overall effect of presenting a distractor near fixation at the same time as the peripheral saccade target, excluding trials on which one of the items matched the color being held in WM. Figure 4 shows the probability that the first saccade landed in the target region (as a proportion of the total number of first saccades) for distractor-absent and distractor-present trials, along with saccade onset time for these eye movements.

When no distractor was present, saccade accuracy was near ceiling for both PSZ and HCS, leading to nearly equivalent group means. Saccade latencies, which are not limited by ceiling effects, were also nearly identical for PSZ and HCS. This replicates previous studies showing that PSZ are not impaired at the overall timing or direction of simple prosaccades (Crawford, Haeger, Kennard, Reveley, & Henderson, 1995; Fukushima, Morita, Fukushima, Chiba, Tanaka, & Yamashita, 1990). When a distractor was present, however, both accuracy and latency were impaired much more in PSZ than in HCS. Whereas the presence of a distractor led to only a 6% drop in accuracy and a 30 ms increase in latency for HCS, the distractor led to a 16% drop in accuracy and a 55 ms increase in latency for PSZ. Note that saccades that were not directed to the target were almost always directed toward the distractor rather than being random for both PSZ and HCS (Figure 2).

To assess the statistical significance of these differences, the accuracy and latency data were entered into separate ANOVAs with factors of group (PSZ vs. HCS) and trial type (distractor present vs. absent). The larger effect of distractor presence on accuracy in PSZ than in HCS led to a significant group \times trial type interaction [$F(1, 65) = 9.58, p = .003$], but the corresponding interaction for saccade latency did not reach significance [$F(1, 65) = 2.77, p = .101$]. The fact that the accuracy effect was significant but the latency effect did not reach significance should not be taken to indicate that there is anything fundamentally different about these measures, especially given that both effects went in the same direction. For both accuracy and latency, the group effect was significant [accuracy: $F(1, 65) = 4.20, p = .044$; latency: $F(1, 65) = 4.72, p = .033$], as was the main effect of trial type [accuracy: $F(1, 65) = 47.03, p < .001$; latency: $F(1, 65) = 32.34, p < .001$].

These results show that the mere presence of a distractor near the fixation point caused a large and significant decrease in the accuracy of saccades to the peripheral target in PSZ compared to HCS. This is consistent with hyperfocusing on stimuli in the region of the fixation point (although it could also be explained by a general impairment in directing gaze toward task-relevant information in the presence of salient distractors; see Discussion for additional consideration of this possibility).

Effect of Memory Match on Eye Movements in the Presence of a Distractor

To examine the hypothesis that PSZ have more intense WM representations, we examined the effect of whether the target or the distractor matched the color being held in WM when a distractor was present. Because a distractor was always present in these trials, saccade accuracy was quantified as the probability of the first saccade landing in the target region relative to the sum of the target region and the distractor region.

In this paradigm, healthy young adults exhibit faster and more accurate saccades to the target when it matches memory, and they exhibit slower and less accurate saccades to the target when the distractor matches memory (Hollingworth et al., 2013b). As shown in Figure 5, we found this same pattern in both HCS and PSZ, but the distractor effects were larger in PSZ than in HCS. That is, the presence of a memory-matching distractor produced a 41% drop in accuracy and a 58-ms increase in latency in PSZ but only a 31% drop in accuracy and a 20-ms increase in latency in HCS (relative to no-match trials). The benefit of a matching target was small and approximately the same for both groups.

To assess the statistical significance of these effects, the accuracy and latency data were entered into separate ANOVAs with factors of group and trial type (no match, distractor match, and target match). The group main effect, the trial type main effect, and the group \times trial type interaction were all significant for the latency measure [group: $F(1, 65) = 14.04, p < .001$; trial type: $F(2, 130) = 38.02, p < .001$; interaction: $F(2, 130) = 4.76, p = .010$]. Follow-up analyses showed that the group \times trial type interaction was significant when comparing distractor-match trials with no-match trials [$F(1, 65) = 6.79, p = .011$] but not when comparing target-match trials with no-match trials [$F < 1$]. Thus, despite the fact that PSZ exhibited poorer memory than HCS, PSZ exhibited a significantly larger saccade latency cost than HCS when the distractor matched memory (on trials when a memory was present).

For accuracy, the main effects of trial type and group were both significant [$F(2, 130) = 88.92, p < .001$ and $F(1, 65) = 12.69, p = .001$, respectively]. However, although the effect of a memory-matching distractor on saccade accuracy was 10% larger in PSZ than in HCS, the group \times trial type interaction was not significant [$F(2, 130) = 1.382, p = .252$]. The fact that the accuracy effect was significant but the latency effect did not reach significance should not be taken to indicate that there is anything fundamentally different about these measures, especially given that both effects went in the same direction. The difference may reflect lower measurement reliability for accuracy measures than for latency measures, or it may simply reflect random normal variation.

These results demonstrate that, when PSZ have an item in WM (as indicated by correct performance on the WM task), the match between this item and a distractor leads to greater allocation of attention to the distractor. This is exactly what would be expected if the WM representations, when present, were more intense in PSZ than in HCS.

Effect of Target Memory Match on Eye Movements in the Absence of a Distractor

We next examined the effect of whether the saccade target matched the color being held in WM when no distractor was present. As shown in Figure 6, saccade accuracy was near

ceiling for both groups irrespective of whether the target matched memory, and no main effects or interactions were significant in an ANOVA with factors of group and memory match. For both groups, saccade latencies were slightly faster when the target matched working memory than when it did not match, but the main effect of trial type was only marginally significant [$F(1,65) = 3.75, p = .057$] and neither the main effect of group nor the group x trial type interaction approached significance [$F < 1$]. Thus, the match between the target and working memory had at best a small effect, whether a distractor was present (Figure 5) or absent (Figure 6). This effect was similar in PSZ and HCS, but it was so small that it would be difficult to detect a difference between PSZ and HCS in the size of this effect (which was comparable to that observed previously in healthy young adults by Hollingworth et al., 2013b).

Spatial Hyperfocusing: Hypometric Saccades

Our final set of analyses examined the amplitude of the eye movements when the eyes moved in the correct direction. Figure 2 shows scatterplots of the landing positions of the eye movements that were large enough to leave the fixation region. The data are shown separately for trials that did or did not include a distractor (in all cases, no item matched the color being held in WM). Even in the simplest trial type, in which a target appeared without a distractor, PSZ made far more saccades that landed at least 1° short of the target than did HCS. This does not reflect poor calibration or off-task performance, because almost all of the saccades landed in the direction of the target on no-distractor trials rather than being the kinds of random responses that would occur as a result of poor calibration or off-task performance. The same pattern can be observed for distractor-present trials: compared to HCS, PSZ exhibited a greater proportion of saccades that went in the direction of the target but fell short, along with more saccades that went to the distractor. Again, this does not reflect poor calibration or off-task performance, because very few eye movements went to the region opposite to the distractor or opposite to the target.

To quantify this apparent difference between groups, we computed the average landing error of the first eye movement to land in the target area on each trial. Because the target varied in location from $4.38\text{--}8.13^\circ$ to the left or $4.38\text{--}8.13^\circ$ to the right of the fixation cross, the landing error on a given trial was expressed as the horizontal difference between the location of the landing point and the center of the target on that trial. Left-target and right-target trials were combined after reflecting all the positions about the vertical meridian on left-target trials. Preliminary analyses suggested that the difference in landing error between PSZ and HCS did not vary systematically across trial types, so the data were aggregated across all trials with a saccade target.

The mean landing error was 0.98° in PSZ and 0.62° in HCS, a significant difference [$t(65) = -3.03, p = .002$]. Thus, PSZ undershot the target by 58% more than did HCS, which is consistent with the hypothesis that PSZ tend to hyperfocus on fixation, leading to competition between the fixation motor goal and the saccade motor goal.

To rule out the possibility that the large number of hypometric saccades in PSZ reflects a general impairment in maintaining fixation, we ran a control task in most of the participants (33 PSZ and 29 HCS). This task assessed the ability of each participant to maintain fixation

in the absence of a task. The stimuli were the same as in the main task, but participants were instructed to ignore the stimuli and simply maintain fixation on the central cross for the duration of the trial. Ninety trials were tested in this condition, which was always conducted at the end of the session. A participant's ability to maintain fixation in this control condition was quantified as the percentage of trials on which fixation was maintained within 1° of fixation point over the entire trial. The mean percentage was actually slightly higher in PSZ (86.0%) than in HCS (83.2%), and this difference did not approach significance, $t(60) = .800, p = .427$. Thus, the large number of hypometric saccades exhibited by PSZ in the main experiment cannot be explained by a general deficit in maintaining fixation, poor calibration, or some other nonspecific factor.

The increase in hypometric saccades exhibited by PSZ replicates previous studies (Everling et al., 1996; Hutton et al., 2001; Leonard et al., 2013) and provides additional evidence that PSZ hyperfocus on the fixation point, creating competition between the fixation point vector and the saccade target vector.

Correlations

We computed Pearson r correlation coefficients to examine the relationship between two measures of hyperfocusing (memory hyperfocusing: the difference in latency between trials with memory-matching versus memory-mismatching distractors; and spatial hyperfocusing: the mean landing error) and measures of cognitive function (WASI IQ), symptoms (BPRS positive symptoms and SANS), and medication dosage (Chlorpromazine equivalent). None of the correlations differed significantly between PSZ and HCS, so the data were collapsed across groups² (except for the symptom and medication measures, which were obtained only for PSZ). We found that memory hyperfocusing and spatial hyperfocusing were significantly correlated ($r = 0.322, p = .008$). In addition, both measures were significantly correlated with WASI IQ (memory hyperfocusing: $r = .285, p = .019$; spatial hyperfocusing: $r = .322, p = .008$). In PSZ, neither measure was significantly correlated with the SANS score, the BPRS positive symptoms score, or the medication dosage ($r < .15, p > .4$ for all of these correlations).

Discussion

This study was designed to assess two varieties of hyperfocusing in PSZ. One variety is spatial, namely enhanced allocation of attention to the fixation point and the surrounding region. A second variety is mnemonic, namely more intense representations in WM. We will begin by discussing mnemonic hyperfocusing and then move on to spatial hyperfocusing.

Hyperfocusing in Working Memory

We assessed the intensity of the WM representations by measuring the capture of attention produced by a distractor object that matched the color of an object being stored in WM. We limited our analyses to trials on which participants actually had a WM representation to avoid confusing the probability of storage with the intensity of storage. Even though PSZ were less likely to have a WM representation than HCS, they did have a representation on a reasonably high proportion of trials (as indexed by correct performance on the WM task).

On this subset of trials, their gaze was slowed considerably by a distractor that matched the color being held in WM, and this effect was larger for PSZ than for HCS. This is exactly what would be expected if schizophrenia is associated with aberrant hyperfocusing on the item in WM, creating a more intense representation of this item even though this was counterproductive for the eye movement task. These results also converge with the finding of a larger CDA for PSZ than for HCS when a single item was held in WM (Leonard et al., 2012). Together, these results show that WM representations of a single simple object are associated with a more intense neural signal and with a greater impact on behavioral performance in PSZ relative to HCS. We should note, however, that these results were obtained in chronic, medicated, clinically stable outpatients, and we do not yet know whether they would generalize beyond this population. In addition, there is no way of knowing at this point whether hyperfocusing is present broadly in PSZ or whether it is limited to specific subgroups. However, like most other measures of narrowly defined cognitive variables, our hyperfocusing measures were not correlated with symptom measures or medication dosage.

Given that many studies have found impaired WM in PSZ (reviewed by Lee & Park, 2005), it may seem surprising that WM representations would be more intense in PSZ than in HCS. However, the impaired WM performance of PSZ mainly reflects deficits in the number of items that can be encoded into WM (Gold et al., 2006; Gold, Hahn, Zhang, Robinson, Kappenman, Beck, & Luck, 2010; Lee & Park, 2005), so the previous results do not conflict with the finding that WM representations, when successfully formed, are more intense in PSZ than in HCS. Moreover, intense WM representations were presumably suboptimal in the present task, because they may lead to incorrect eye movement trials when the distractor matches the color in WM. Thus, even if WM representations can be just as intense in HCS as in PSZ when the task requires it, PSZ may be unable to control the intensity of their WM representations, focusing maximally even when this is suboptimal for a given task.

One might expect that more intense WM representations would also be more durable and more resistant to distraction. If anything, though, PSZ exhibit less durable WM representations and greater effects of distraction in WM (Anticevic, Repovs, Corlett, & Barch, 2011; Anticevic, Repovs, Krystal, & Barch, 2012). However, durability and resistance to distraction may depend much more on active mechanisms for preventing interference rather than on the intensity of the WM representations (Clapp, Rubens, & Gazzaley, 2010; Frank, Loughry, & O'Reilly, 2001).

Could the present results instead be explained by a general impairment of attentional control in PSZ? If the distractor is more salient when it matches WM, and PSZ have a general attentional deficit that makes them more distractible, then this could explain the greater impact of the WM-matching distractor in PSZ. However, PSZ do not usually appear to have a *general* deficit in attentional control that makes them more distractible in all tasks. For example, using a well-validated task that is known to yield increased distraction effects in lesion patients, Erickson et al. (submitted) found no more distraction in PSZ than in HCS in two separate experiments. In addition, four separate experiments using a cued working memory paradigm found no evidence of an impairment in distractor suppression in PSZ (Gold et al., 2006). Moreover, a recent meta-analysis of 21 studies of flanker interference

found no evidence of greater distraction in PSZ than in HCS (Westerhausen, Kompus, & Hugdahl, 2013). Finally, PSZ do not show exaggerated capture of attention by salient but irrelevant “pop-out” colors in a task that is commonly used to measure distraction in the basic cognitive science literature (Leonard, Robinson, Hahn, Gold, & Luck, in press). Thus, although PSZ exhibit greater distraction than HCS under some conditions, they do not exhibit a *general* impairment in attentional control that could explain the present finding of greater distraction by items that match the contents of WM. Instead, the best explanation is that WM representations are actually more intense in PSZ than in HCS under certain conditions, leading to greater capture of attention by items that match the contents of WM. This result is counterintuitive because one would ordinarily expect weaker effects of WM in PSZ, but it was directly predicted by the hyperfocusing hypothesis.

The present study also found that patients were more distracted than were controls for distractors that did not match working memory. This effect could be explained in two ways. First, the distractor was a potent stimulus for activating the magnocellular pathway, which previous research shows can lead to greater capture of attention in PSZ (Erickson et al., submitted; Gold et al., 2006; Hahn, Robinson, Kaiser, Harvey, Beck, Leonard, Kappenman, Luck, & Gold, 2010; Leonard et al., in press). Second, the distractor was much closer to the fixation point than was the target, and as the next section will describe, PSZ may hyperfocus on the fixation point and surrounding region. This contrasts with the flanker paradigm—in which the target is at fixation and the flankers are lateralized—which does not produce consistent evidence of greater distraction in PSZ than in HCS (Westerhausen et al., 2013).

It should be noted that some of the effects were significant for both the latency and accuracy measures, whereas others were significant for one but not the other. However, the effects always went in the same direction for both measures, and the differences in significance could simply reflect occasional Type II errors resulting from normal variability in measures of behavior. The observed pattern could also reflect differences in speed-accuracy tradeoffs across conditions. For this reason, it is useful to measure both the speed and accuracy of saccadic eye movements in paradigms of this nature.

Spatial Hyperfocusing

The present study also found evidence for spatial hyperfocusing in PSZ. If schizophrenia is associated with excessive attention to the fixation point and surrounding region, then this should create exaggerated competition between this region and the region containing the target. By analogy, studies in nonhuman primates found that attentive fixation of a central spot led to decreased saccadic amplitudes in response to peripheral targets (hypometric saccades) (Pare et al., 1994; Schiller & Sandell, 1983). Consistent with this prediction, we found that target-elicited saccades undershot the target more in PSZ than in HCS. We recently found a similar pattern of hypometric saccades in a simple prosaccade task (Leonard et al., 2013). A control condition in the present study ruled out the possibility that this pattern simply reflects poor fixation ability in the absence of a task.

If this spatial hyperfocusing extends to the region immediately surrounding the fixation point, then it would be expected to increase the probability of saccades to distractors that are near fixation. Consistent with this, we found that the nearby distractors in the present study

were more likely to be fixated by PSZ than by HCS. However, we did not systematically vary the eccentricity of the distractor, so additional research would be needed to demonstrate that this distraction effect is limited to the region surrounding the point of fixation.

Note that our measure of spatial hyperfocusing was significantly correlated with our measure of mnemonic hyperfocusing. This suggests that they may reflect a common underlying deficit, although there are many possible explanations for a simple correlation of this nature.

Possible Neural Mechanisms

Hyperfocusing could result from changes in neural network dynamics produced by abnormalities in specific neurotransmitter systems. Computational neuroscience studies (reviewed by Durstewitz & Seamans, 2008; Rolls, Loh, Deco, & Winterer, 2008) have shown that the D1 and D2 classes of DA receptors interact with NMDA- and GABA-mediated processes to produce two competing attractor states: a) a D1-dominated state with deep basins of attraction that lead to exaggerated *winner-take-all* dynamics; and b) a D2-dominated state with shallow basins of attraction that promote flexibility and rapid updating of representations. The known pathophysiology of schizophrenia is consistent with a disruption of these competing network states, and one possibility is that PSZ are biased toward the D1-dominated state that emphasizes winner-take-all processing.

The D1-dominated state would be expected to produce more intense WM representations because of an increase in NMDA-mediated recurrent excitation, and it would also be expected to produce reduced WM capacity because of increased inhibition that “leads to fiercer competition among different active ensembles of neurons” (Durstewitz & Seamans, 2008, p. 741). Thus, PSZ may get trapped in the D1-dominated state, leading to a smaller number of more intense representations, even when this is not optimal for the current task. In contrast, HCS can presumably enter this state when it is optimal for the task, but they can more easily enter the D2-dominated state when it is adaptive to do so.

The present hypothesis is at odds with prior evidence suggesting an increase in striatal D2-related activity in PSZ (e.g., Abi-Dargham, Rodenhiser, Printz, Zea-Ponce, Gil, Kegeles, Weiss, Cooper, Mann, Van Heertum, Gorman, & Laruelle, 2000). However, there are also findings suggesting that long-term changes in DA in PSZ lead to an upregulation of prefrontal D1 receptors that are associated with working memory deficits (Abi-Dargham, Mawlawi, Lombardo, Gil, Martinez, Huang, Hwang, Keilp, Kochan, Van Heertum, Gorman, & Laruelle, 2002). More research is needed to understand how D1 and D2 receptor activity is altered in PSZ.

Although clearly speculative, our proposal of D1-dominated networks dynamics could potentially explain hyperfocusing both in attention and in working memory. Consistent with this, we have recently found that PSZ exhibit an impairment in the ability to divide attention between a central target and a simultaneous peripheral target in the *Useful Field of View* task, and that this impairment is strongly correlated with reduced WM capacity (Gray, Hahn, Robinson, Harvey, Leonard, Luck, & Gold, in press). Moreover, the shared variance between these two tasks was associated with impairments in broad cognitive function (e.g.,

WASI IQ). Thus, a single mechanism may underlie deficits in both attention and WM in schizophrenia.

Hyperfocusing, Perseveration, and Task Maintenance

Our hyperfocusing hypothesis is intended to explain impairments in visual processing, but it may also be able to explain deficits in postperceptual processing. In particular, if PSZ tend to hyperfocus on task representations, this would make it more difficult for them to switch to a new task representation, leading to perseveration. For example, after being rewarded for responding according to one dimension in the Wisconsin Card Sorting Test, hyperfocusing on this dimension may cause PSZ to perseverate on this dimension when the task changes. While speculative, this is a potential explanation for the common finding of greater perseveration in PSZ (Crider, 1997).

This same idea may be able to account for deficits in some variants of the Continuous Performance Task (CPT). In the basic CPT, a target stimulus (e.g., the letter X) appears infrequently in a stream of nontargets. PSZ tend to miss the targets more often than HCS, which is not easily explained by hyperfocusing but may reflect general failures in task set (Barch, Berman, Engle, Jones, Jonides, Macdonald III, Nee, Redick, & Sponheim, 2009; Barch et al., 2012). This is analogous to the lower accuracy of PSZ relative to HCS in the WM component of the present task. However, when PSZ have a task representation in CPT tasks, this representation might be more intense than that of controls. This is difficult to test in the standard CPT, but it could potentially explain the result of experiments using the “expectancy AX” variant of the CPT. In this variant, an X is a target only if preceded by an A, which happens on the vast majority of trials. Thus, this task encourages a strong link between the letter X and the target response that must be overcome if the X is preceded by another letter (e.g., B). If the intensity of the X-target link is even stronger in PSZ than in HCS, it would be more difficult for PSZ to overcome this link on BX trials and make the correct nontarget response instead of the prepotent target response. This might explain the finding of more BX errors in PSZ than in HCS (Servan-Schreiber, Cohen, & Steingard, 1996). Indeed, it might explain why these BX errors are more common than other kinds of errors in PSZ (Barch et al., 2009), because these are the trials on which a prepotent response must be overcome. This does not deny that impairments in encoding or maintaining the context stimulus (the A or B) play a role in this task, but it explains the potential role of a prepotent stimulus-response link in this task.

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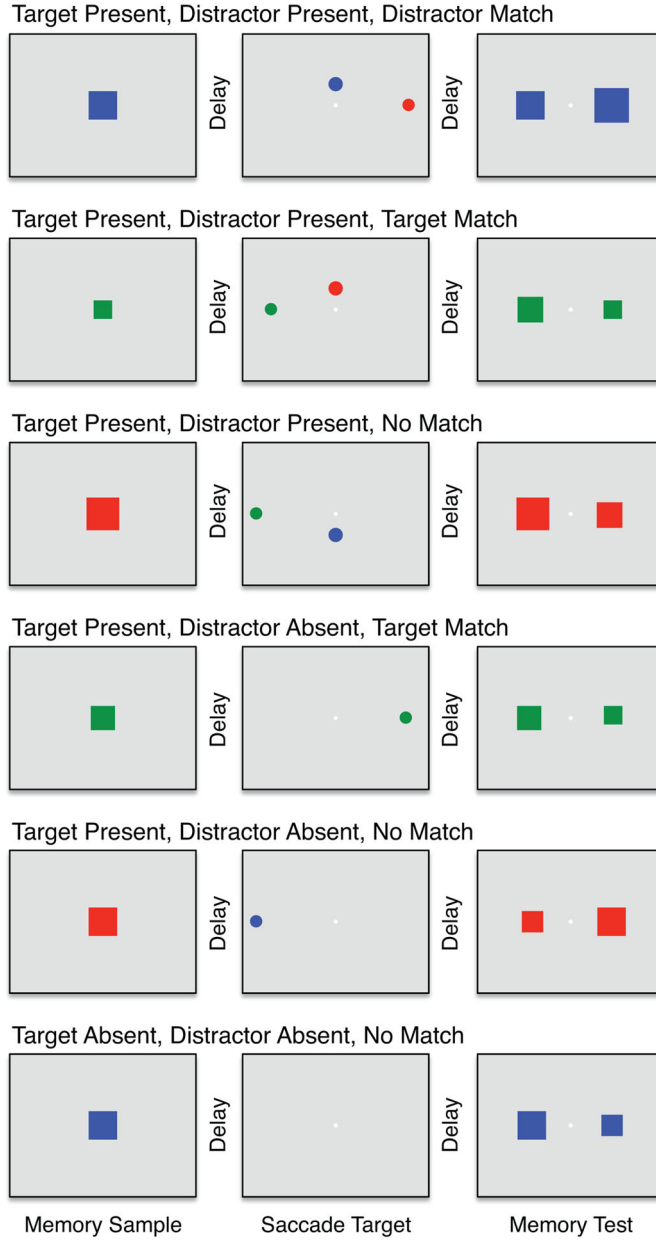


Figure 1. Examples of each of the six main trial types. On every trial, participants received a sample square at the beginning and a test display at the end, and they indicated which of the two test squares exactly matched the size of the sample square. On most trials, an eye movement target appeared to the left or right of fixation during the delay interval of the memory task. The target was sometimes accompanied by a distractor that was positioned just above or just below the fixation point. The target or distractor sometimes matched the color of the sample square. Color was formally task-irrelevant, but people will store the color of an object in working memory if they store other features of the object (Hollingworth et al., 2013b; Hyun et al., 2009).

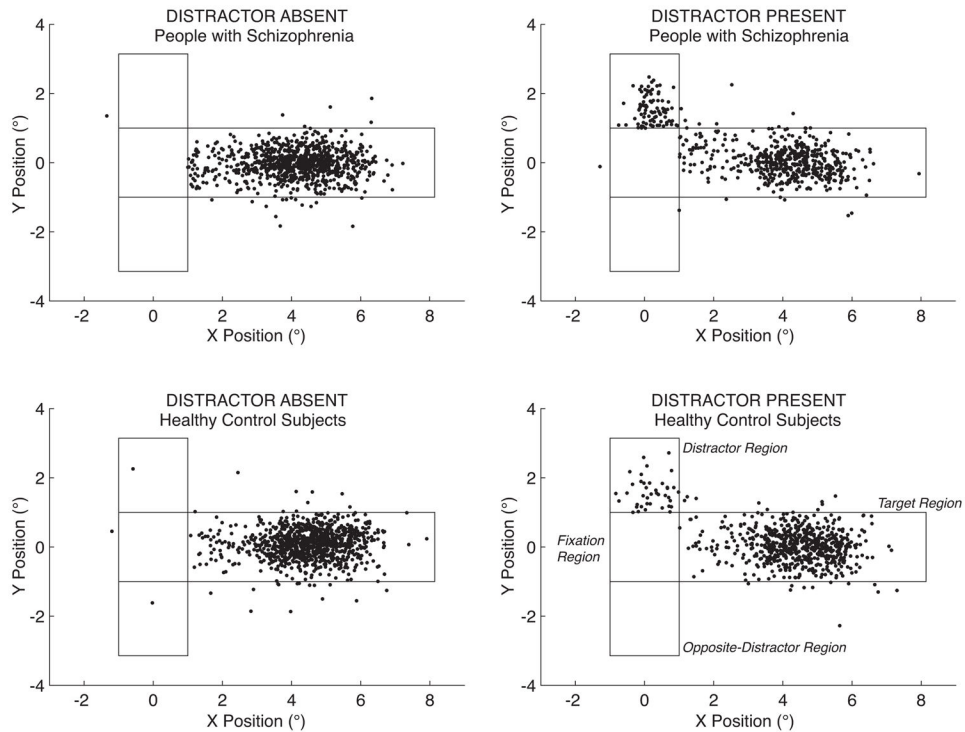


Figure 2. Landing positions of the eye movements on distractor-absent (left) and distractor-present (right) trials in people with schizophrenia (top) and healthy control subjects (bottom). Each dot represents an individual eye movement landing point. Rectangles indicate the areas used to define eye movements to the target, to the distractor, and to the region opposite to the distractor. Landing positions have been reflected about the horizontal and vertical axes, when appropriate, as if the target was always on the right side of fixation and the distractor was always above fixation. In these data, neither the target nor the distractor matched the memory color.

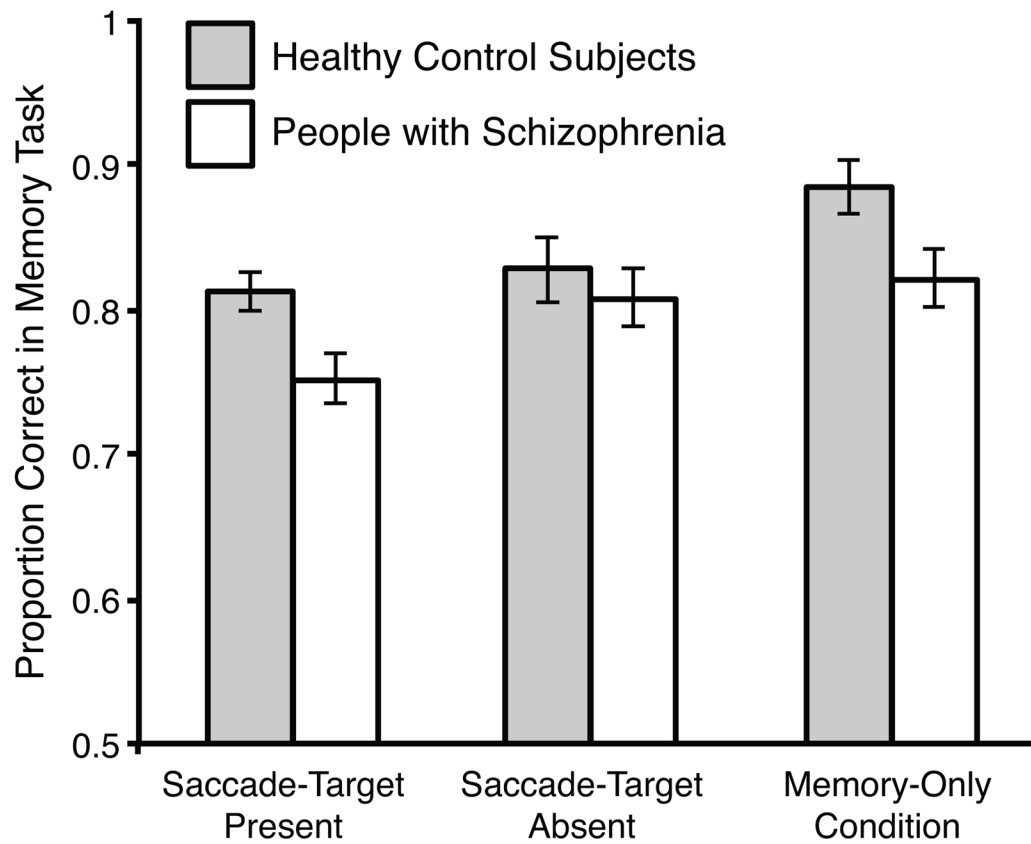


Figure 3. Proportion correct in the memory task when a saccade target was present, when a saccade target was possible but absent, and in the memory-only condition in which saccade targets were never presented. The data were collapsed across trials in which a distractor was or was not present at the time of the target. Error bars show the standard error of the mean.

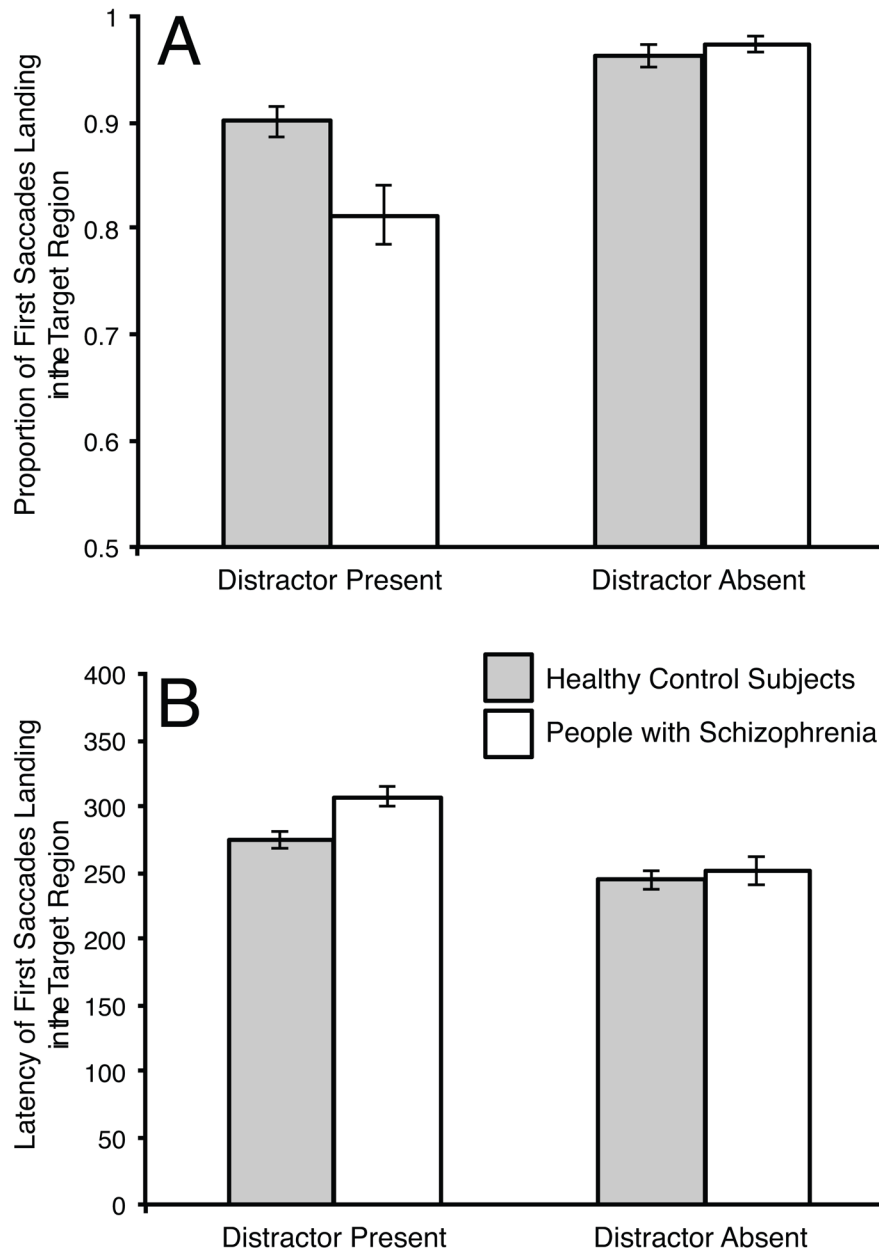


Figure 4. Effects of distractor presence on eye movements, excluding trials on which one of the items matched the color being held in WM. Group means are shown for the proportion (A) and latency (B) of first saccades that landed in the target region on distractor-present and distractor-absent trials. Error bars show the standard error of the mean.

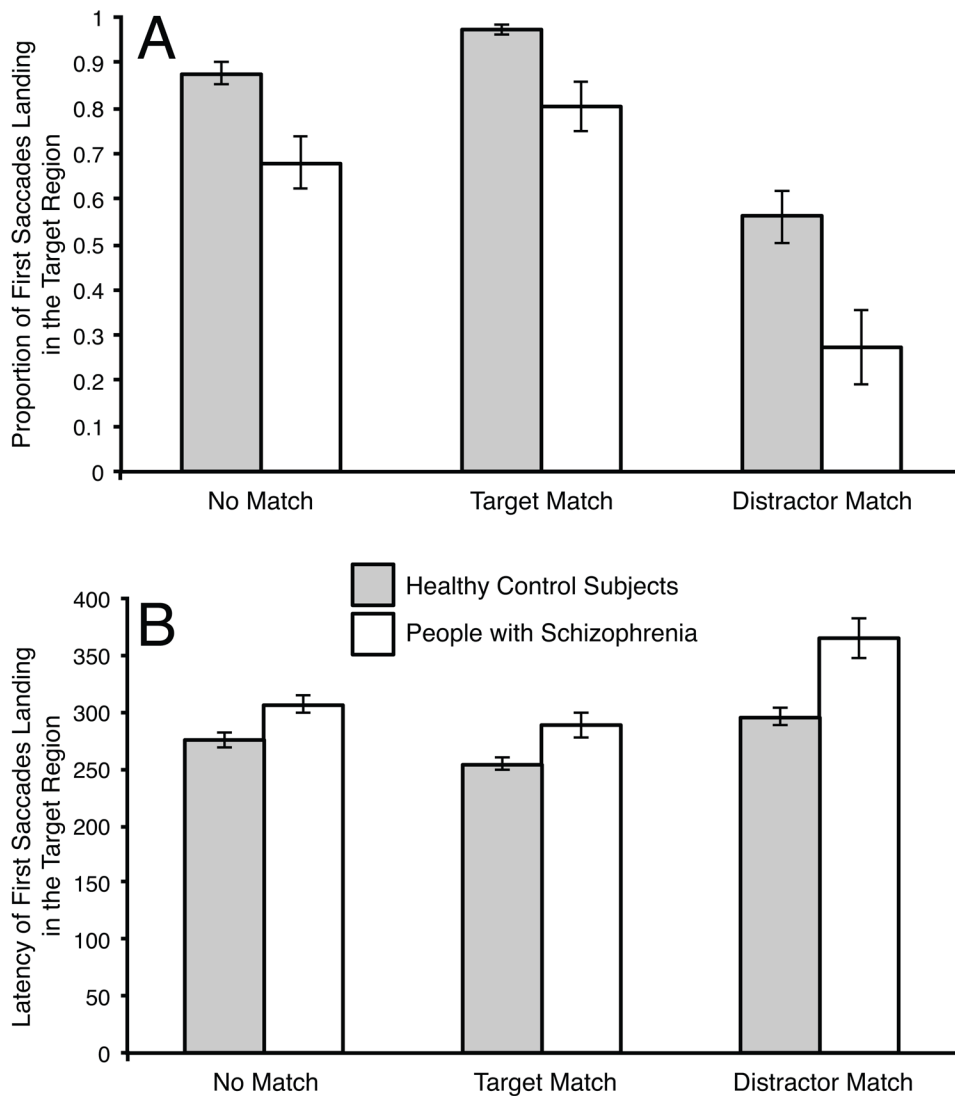


Figure 5. Effects of memory match on eye movements for trials on which a distractor was present. (A) Group means for the proportion of first saccades that landed in the target region when neither the target nor the distractor matched the memory item, when the target matched the memory item, and when the distractor matched the memory item. The proportion reflects the number that landed within the target region divided by the number that landed either within the target region or the distractor region. (B) Group mean latency for the saccade types shown in (A). Error bars show the standard error of the mean.

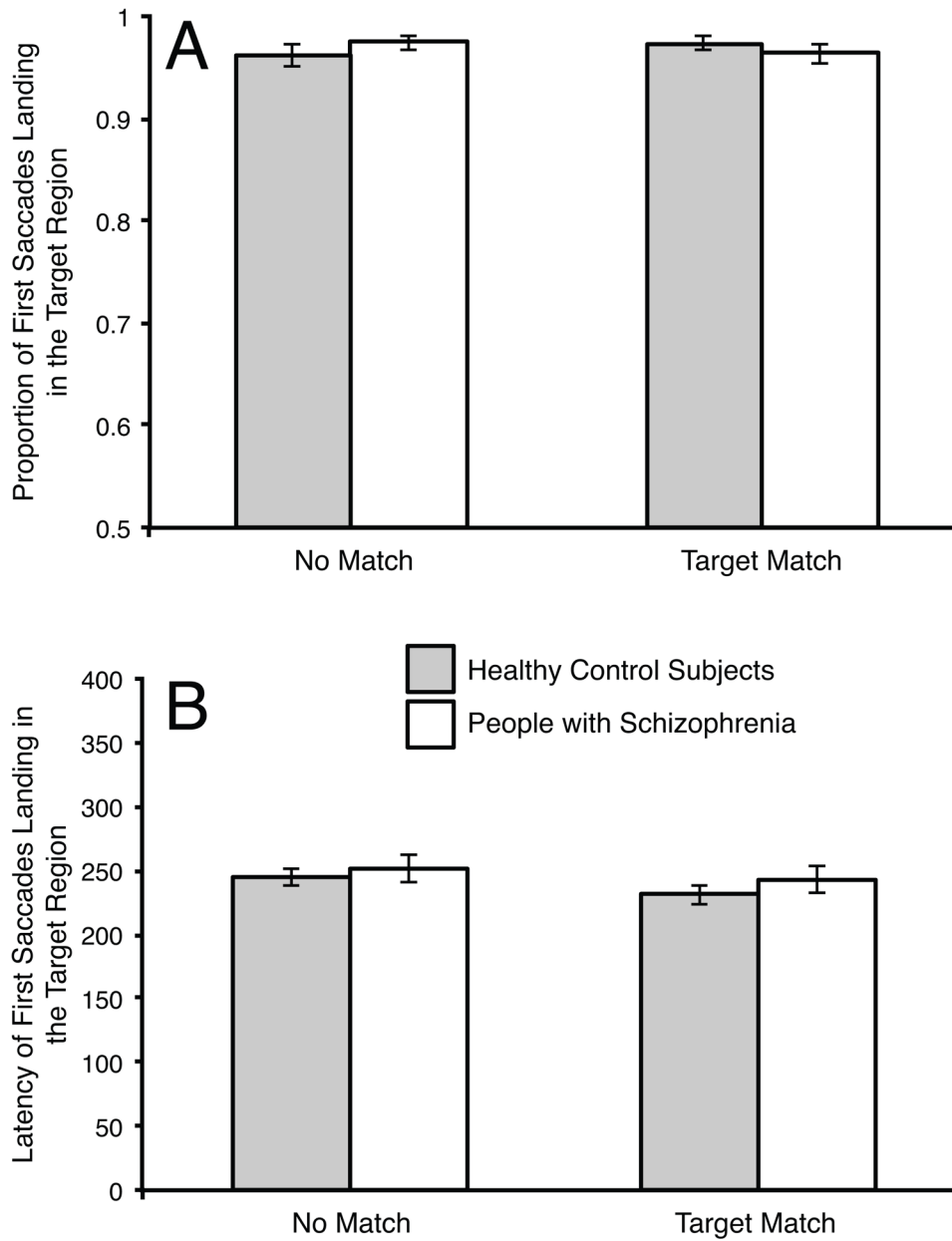


Figure 6. Effects of memory match on eye movements for trials without a distractor. Group means are shown for the proportion (A) and latency (B) of first saccades that landed in the target region when the target did and did not match the memory item. Error bars show the standard error of the mean.

Table 1Group demographics (mean \pm standard deviation)

	PSZ	HCS
Age	34.4 \pm 10.2 (range 19–56)	35.2 \pm 10.5 (range 18–57)
Male : Female	22 : 11	22 : 12
AA : A : C : M^a	13 : 1 : 19 : 0	13 : 0 : 20 : 1
Parental education^b	14.0 \pm 2.2 ^c	14.3 \pm 2.2
WASI	105.1 \pm 12.8 ^d	116.4 \pm 11.7 ^{c **}
WRAT 4 standard score	102.5 \pm 11.6 ^e	110.7 \pm 14.1 ^{c *}
WTAR standard score	106.4 \pm 12.4 ^e	112.3 \pm 12.6 ^c
MATRICES total score	36.2 \pm 13.5 ^e	56.7 \pm 8.8 ^{c **}
BPRS^f total score	35.1 \pm 7.1 (range 21–54)	
SANS^g total score	25.4 \pm 9.3 (range 10–43)	
LOFS^h total score	20.8 \pm 5.0 (range 13–29)	
CDSⁱ total score	2.0 \pm 2.7 (range 0–10)	

^a AA = African American; A = Asian; C = Caucasian; m = Mixed race^b average over mother's and father's years of education^c data unavailable for 1 subject^d data unavailable for 3 subjects^e data unavailable for 2 subjects* $p < 0.05$,** $p < 0.001$; significant difference between PSZ and HCS in independent samples t-test^f Brief Psychiatric Rating Scale (Overall & Gorham, 1962)^g Scale for the Assessment of Negative Symptoms (Andreasen, 1984)^h Level Of Functioning Scale (Hawk, Carpenter, & Strauss, 1975)ⁱ Calgary Depression Scale (Addington, Addington, Maticka-Tyndale, & Joyce, 1992)