Hyperfocusing of Attention on Goal-Related Information in Schizophrenia: Evidence From Electrophysiology

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Schizophrenia clearly involves impairments of attention, but the precise nature of these impairments has been difficult to determine. One possibility is that the deficit in attention is a secondary consequence of a deficit in goal maintenance. However, recent research suggests that people with schizophrenia (PSZ) actually focus attention more strongly on objects containing goal-relevant features. To test these competing hypotheses, we recorded event-related potentials (ERPs) from PSZ ($N = 20$) and healthy control subjects (HCS; $N = 20$) while they looked for a particular target color at fixation and tried to ignore lateral distractors that sometimes matched the target color (target-color distractors). Goal maintenance was made trivially easy by the continual presentation of a goal reminder. We found that HCS were able to successfully suppress target-color distractors (leading to a distractor positivity ERP component), whereas PSZ focused attention on these items (leading to an N2-posterior-contralateral ERP component). This suggests that, when maintaining a task set, PSZ engage in aberrant focusing of attention, or hyperfocusing, on goal-relevant features.

General Scientific Summary
Using electrophysiological measures of attentional enhancement and suppression, the present study supports the notion that people with schizophrenia focus attention more intensely than healthy controls on objects that partially match task goals.

Keywords: schizophrenia, attention, distraction, hyperfocusing, event-related potentials

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It is widely believed that one of the core symptoms of people with schizophrenia (PSZ) is a deficit in attention (Barch, Carter, Hachten, Usher, & Cohen, 1999; Braff, 1993; Heinrichs, 2005; Kozak et al., 2007). However, the term *attention* refers to many distinct cognitive processes and is achieved by a broad set of neural systems (Luck & Gold, 2008; Luck & Vecera, 2002), and it has been difficult to identify the specific attentional mechanisms

that are impaired in PSZ. One possibility is that PSZ have trouble maintaining goals, and their attention fails simply because their goal representations fade. Indeed, there is substantial evidence for impaired goal maintenance in PSZ (Barch & Smith, 2008). This impairment is most evident under conditions that challenge goal maintenance by changing the goal from trial to trial, by imposing delays between the goal cue and the target, and by using goals that require overcoming prepotent responses (Cohen, Barch, Carter, & Servan-Schreiber, 1999; Servan-Schreiber, Cohen, & Steingard, 1996). By contrast, in tasks where the same goal is repeated for many consecutive trials—which keeps the goal primed and minimizes opportunities for interference between competing goals—PSZ often exhibit no deficit in focusing attention on goal-relevant sources of information and filtering irrelevant sources (Erickson et al., 2015; Gold et al., 2006). Thus, it is plausible that the processes that directly underlie selective attention are unimpaired in PSZ and that any observed performance deficits in attention tasks are a secondary consequence of failures in goal maintenance.

However, there is growing behavioral evidence that PSZ exhibit attentional abnormalities that cannot be explained by the fading of goal representations and instead appear to reflect a paradoxical aberrant focusing of attention onto objects that contain goal-

relevant features. For example, Mayer, Fukuda, Vogel, and Park (2012) found that PSZ exhibited exaggerated distraction by nontarget flanker objects that matched the color of a visual search target, which would be possible only if they had successfully maintained the goal of attending to this color. Similarly, Luck et al. (2014) found that PSZ exhibited exaggerated distraction by a nontarget object that matched a color currently being held in working memory.

In both of these cases, PSZ exhibited a maladaptive focusing of attention onto sensory inputs that were related to current task goal representations or working memory representations. This is effectively the opposite of what would be predicted on the basis of a deficit in goal maintenance: Instead of failing to attend to task-related information, PSZ attended too strongly to task-related information. Thus, although prior research indicates PSZ have deficits in maintaining goals under conditions that make goal maintenance difficult, PSZ may exhibit an aberrant focusing of attention onto goal-related information when goal maintenance is easy. This aberrant focusing of attention may interfere with the ability to reject distractors containing goal-relevant features.

The purpose of the present study was to provide converging evidence for this aberrant focusing of attention. We used an ERP task that has previously been used in healthy young adults to examine distraction by stimuli that partially match the current task goals (Sawaki, Geng, & Luck, 2012). As illustrated in Figure 1, participants looked for a stimulus with a particular target color at fixation and tried to ignore adjacent distractor stimuli that sometimes matched the target color (target-color distractors). To make goal maintenance trivially easy, the target color remained constant for a given block of trials, and a letter at fixation continually indicated the current target color.

Our analyses focused on two event-related potential (ERP) components: *N2pc* and P_D. The N2pc (N2-posterior-contralateral) component is a well-validated index of the focusing of attention onto a lateralized object (Luck, 2012; Luck & Hillyard, 1994a,

1994b), and the presence of an N2pc for a distractor reflects capture of attention by this item (Hickey, McDonald, & Theeuwes, 2006). This component is observed at lateral occipital-temporal scalp sites as a more negative voltage at scalp sites contralateral to an attended item (relative to ipsilateral scalp sites), and it typically begins 150–225 ms after stimulus onset. The N2pc component appears to be generated in intermediate and high levels of the ventral visual processing pathway (i.e., V4 and the lateral occipital complex (Hopf et al., 2006; Hopf, Boelmans, Schoenfeld, Luck, & Heinze, 2004).

In contrast, the P_D (distractor positivity) component is an index of suppression (Hickey, Di Lollo, & McDonald, 2009; Luck, 2012), and the presence of a P_D for a distractor indicates that it is not attended and is instead being actively suppressed (Gaspar & McDonald, 2014; Sawaki & Luck, 2010, 2014). This component is observed at lateral occipital-temporal scalp sites as a more positive voltage at scalp sites contralateral to a to-be-suppressed item (relative to ipsilateral scalp sites), and it typically begins 100–400 ms after stimulus onset, depending on the stimuli and task. Although the neural sources of the P_D component are not yet known, the P_D and N2pc component have similar scalp distributions with opposite polarities and complementary roles in attention. Therefore, it is plausible that these components are associated with opposing attentional processes within the same neural sources. Distractors could elicit only an N2pc but not a P_D when attention is completely directed toward them, only a P_D but not an N2pc when attention toward distractors is completely prevented, or an N2pc followed by a P_D when attention is directed toward distractors and then suppressed (for a review, see Sawaki & Luck, 2014).

We predicted that healthy control subjects (HCS), like the healthy young adults in the previous study (Sawaki et al., 2012), would be able to avoid focusing attention onto the target-color distractor as evidenced by the presence of a P_D component to this object. In contrast, we predicted that PSZ would focus attention onto the target-color distractor because it partially matched the task goal, leading to an N2pc instead of a P_D. Because the experiment was designed to make goal maintenance trivially easy, we expected PSZ to fully maintain the task goals, leading to accurate task performance, but to focus attention on the target-color distractors nonetheless.

We also included a measure of visual working memory capacity in the present study to test whether aberrant focusing of attention is associated with reduced working memory capacity. This was suggested by several tasks that involve an aberrant or persistent focusing of attention onto a goal or stimulus, such as the Wisconsin Card Sorting Task (Gold, Carpenter, Randolph, Goldberg, & Weinberger, 1997), the antisaccade task (Kane, Bleckley, Conway, & Engle, 2001; Leonard, Robinson, et al., 2013) and a visual search task that involves suppressing distractors that share the color of the target (Mayer et al., 2012).

Method

Participants

Twenty-four people with schizophrenia or schizoaffective disorder and 20 healthy control subjects participated in this experiment. None had color vision abnormalities as indexed by Ishihara's Test for Color Deficiency. As in our previous ERP studies
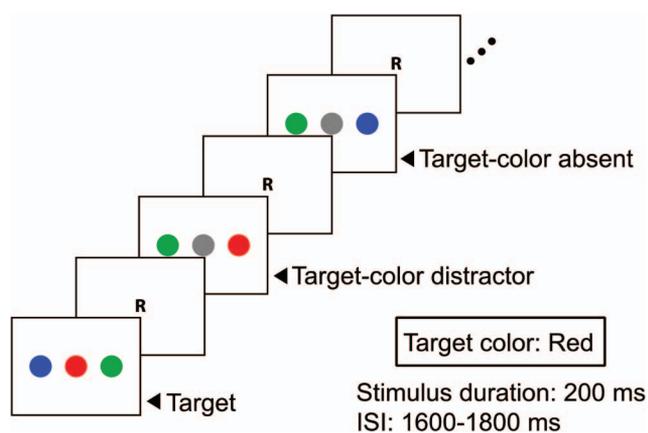
Figure 1. Example stimulus displays. The target was a central circle with the target color (red in this example). The target-color distractor was a circle with target color at a lateral location. Participants were asked to report whether the central circle was the target color or not, ignoring the lateral circles. "R" during ISI served as both a fixation point and a constant reminder of the target color ("red"). ISI = interstimulus interval. See the online article for the color version of this figure.

of schizophrenia, we excluded participants who exhibit artifacts on more than 50% of trials, average residual horizontal electrooculography (EOG) activity exceeding 6.4 μV, or behavioral performance that suggests a failure to understand the task instructions (which was defined as accuracy <50% correct in the present experiment). Four PSZ (3 due to excessive horizontal EOG activity and 1 due to low behavioral performance) and no HCS were excluded for these reasons, yielding a final sample of 20 participants per group. The following descriptions reflect this final sample.

Diagnosis was established using a consensus best estimate approach, which combines material from past medical records, collateral informants (when available), and the results of the Structured Clinical Interview for *DSM–IV–TR* Axis I Disorders (SCID-I; First et al., 2002) to make a diagnosis based on the standard criteria in the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; *DSM–IV*). Final diagnosis of schizophrenia ($N = 17$) or schizoaffective disorder ($N = 3$) was reached at a consensus conference involving clinical staff chaired by James M. Gold. All participants in the PSZ group were clinically stable outpatients who had not changed medication or dosage for at least 4 weeks prior to study participation (3 were receiving typical antipsychotics, 10 were on atypical antipsychotic monotherapy, 5 were receiving two atypical antipsychotics, and 2 were receiving a combination of typical and atypical antipsychotics). Control participants were recruited by random-digit dialing of households in nearby zip codes, Internet advertisements, wall notices, and word of mouth, and they were screened using the complete SCID-I and Axis II Personality Disorders (SCID_IV; Pfhol et al., 1995). Controls had no current diagnosis of any Axis I disorder or Axis II schizophrenia-spectrum disorder, and claimed no lifetime history of psychosis as well as no family history of psychotic disorders in first-degree relatives. As shown in Table 1, the groups were of similar age, parental education level, gender, and ethnicity. However, they differed in completed years of education, $t(38) = 2.3$, $p = .028$, $d = 0.75$, which is typical given that disease onset is generally in early adulthood. In addition, IQ scores were approximately 15 points higher for HCS than for PSZ, $t(36) = 3.5$, $p =$

.001, $d = 1.14$, which is typical given the cognitive impairment that characterizes schizophrenia (Dickinson, Ramsey, & Gold, 2007). The Scale for the Assessment of Negative Symptoms (SANS; Andreasen, 1984) and Brief Psychiatric Rating Scale (BPRS; Overall & Gorham, 1962) were used to measure symptom severity (see Table 1). All participants were free of other medical or neurologic comorbidity that might interfere with test performance, including substance abuse or dependence within the last 12 months. Participants were between the ages of 19 and 54 years of age and gave written informed consent before taking part in the study. The protocol was approved by the institutional review board at the University of Maryland, Baltimore.

Stimuli and Procedure

The task involved responding to a central filled circle of a specific color and ignoring simultaneous flanking circles (see example stimuli in Figure 1). The stimuli were presented on a video monitor with a black background at a distance of 70 cm. Each stimulus array consisted of three solid circles (1.6° in diameter), one at the center of the monitor and the others centered 2.5° to the left and right of center. The color of the central circle was gray on 70% of trials, red ($u' = .46$, $v' = .50$) on 10% of trials, green ($u' = .14$, $v' = .55$) on 10% of trials, and blue ($u' = .19$, $v' = .24$) on 10% of trials. All colors were matched for luminance (18 cd/m²). The color of each lateral circle was red, green, or blue with equal probability (33.3% each). The colors of the three circles in a given array were selected randomly and independently with the designated probability, with the constraint that the two lateral circles were never the same color. Each stimulus array was presented for 200 ms, followed by a variable-duration blank interstimulus interval of 1,600–1,800 ms (rectangular distribution).

At the beginning of each block of trials, one of the colors (red, green, or blue) was designated the target color for that block. For each stimulus array, participants were instructed to press a button on a game pad with the index finger of the dominant hand if the central circle was drawn in the target color, and to press with the middle finger if the central circle was not drawn in the target color. They were explicitly instructed to ignore the lateral distractor items. Thus, a target-absent response was required when a target-color distractor was present in one of the lateral locations and the central circle was not the target color. Speed and accuracy were equally stressed. Each participant performed 60 practice trials, followed by 24 blocks of 60 trials during which electroencephalogram (EEG) was recorded. There were 8 blocks for each attended color, occurring in random order.

Our main prediction was that PSZ would be more likely to attend rather than suppress a distractor if it was drawn in the same color as the target (a target-color distractor). To facilitate goal maintenance, a gray letter *R*, *G*, or *B* (0.5° × 0.5°, 18 cd/m²) was present in the center of the display throughout each interstimulus interval of a given trial block to serve as both a fixation point and a constant reminder of the target for that block.

One of the two lateral circles was a target-color distractor in 67% of stimulus arrays. The central circle could, by chance, be the same color as one of the lateral circles, but those very rare trials were excluded from data analysis. Only trials in which the central location had a gray circle were included for analyses of the target-absent trials (672 trials, 47%). Participants were required to

Table 1
Demographic Features of Sample (Mean ± Standard Deviation)

Demographic variable	HCS	PSZ
Age	40.7 ± 10.7	39.9 ± 10.1
Education (years)[a]	4.6 ± 1.8	13.2 ± 2.0
Mother's education (years)	13.4 ± 2.3	13.1 ± 2.2
Father's education (years)[b]	13.9 ± 2.6	13.7 ± 3.3
Gender (male:female)	4:6	14:6
Ethnicity (C:AA:other)	12:8:0	12:7:1
IQ[a,b]	115.8 ± 10.8	100.9 ± 14.9
SANS total[c]		25.5 ± 12.0 (range: 9–0)
BPRS total[c]		35.6 ± 7.9 (range: 26–4)
BPRS negative symptom		1.6 ± 0.6 (range: 1–2.8)
BPRS positive symptom		2.6 ± 1.4 (range: 1–5.3)
BPRS disorganized symptom		1.5 ± 0.4 (range: 1–2.2)

Note. HCS = healthy control subjects; PSZ = people with schizophrenia; C = Caucasian; AA = African American; SANS = Scale for the Assessment of Negative Symptoms (Andreasen, 1984); BPRS = Brief Psychiatric Rating Scale (Overall & Gorham, 1962).
[a] Significant difference between HCS and PSZ.   [b] Data missing for two patients.   [c] Data missing for one patient.

maintain central fixation throughout the trial, verified with EOG recordings.

We also measured visual working memory capacity in each participant using a well-validated change localization task (in a different session, without EEG recordings). The methods were identical to those used in a previous study (Johnson et al., 2013), which demonstrated that PSZ have a large reduction in working memory capacity that is strongly correlated with measures of broader cognitive function. Each trial began with a 100-ms sample array containing four $0.7° \times 0.7°$ colored squares, arranged around an invisible circle with a radius of 3° and at least 30° of separation between squares (see Johnson et al., 2013, for additional details). After a blank 900-ms delay period, a test array was presented; this array was identical to the sample array except that one square changed to a new color. Participants identified which of the squares changed color by selecting it with a mouse. Percentage correct was converted into K, an estimate of the number of objects' worth of information that was present in memory (Kyllingsbaek & Bundesen, 2009).

Recording and Analysis

The EEG was recorded using Ag/AgCl electrodes from 14 scalp sites (Fp1, Fp2, F3, F4, F7, F8, C3, C4, P3, P4, P7, P8, O1, and O2, according to the International 10–20 System). Impedance was kept below 10 KΩ. The EEG was recorded with a left-mastoid reference and then rereferenced offline to the average of the left and right mastoids. To detect eye movements and blinks, the EOG was recorded from electrodes placed lateral to the outer canthi and below the left eye. The EOG signals from the outer canthi were recorded with a bipolar horizontal EOG derivation, and the EOG from below the eye was referenced to the average of the mastoids. Signals were amplified, filtered, and digitized with a Neuroscan Synamps amplifier (gain = 5,000; half-amplitude bandpass = 0.05–100 Hz, with a 60-Hz notch filter; sampling rate = 500 Hz).

All data analyses were performed in Matlab using ERPLAB Toolbox (Lopez-Calderon & Luck, 2014) and EEGLAB Toolbox (Delorme & Makeig, 2004). The EEG and EOG signals were bandpass-filtered offline using a noncausal Butterworth infinite impulse response filter with half-power cutoffs at 0.05 and 30 Hz and a roll-off of 12 dB per octave, and then down-sampled to 256 Hz. The EEG signals were collapsed across stimulus locations and colors to eliminate sensory confounds related to these factors.

Trials were automatically excluded if the response was incorrect or if the reaction time (RT) was less than 100 ms or greater than 1,500 ms. A combination of artifact rejection and artifact correction was used to account for eyeblinks. First, to eliminate trials in which the eyes were closed during the period of a stimulus, trials were excluded if the voltage exceeded ±80 μV between 100 ms before and 200 ms after stimulus onset in the FP1, FP2, or vertical EOG electrodes. Then, independent component analysis was used to estimate and subtract eyeblink-related voltages in the remaining trials (Jung et al., 2000). A single blink-related component was identified in each subject by visual inspection and removed. Finally, trials were excluded if the EEG exceeded ±100 μV in any channel, or if a step function applied to the horizontal EOG exceeded 15 μV (see

Luck, 2014, chap. 6). The artifact correction and rejection procedures were executed by Risa Sawaki, who was blind to group membership at that time. To assess whether any systematic horizontal EOG activity was present in the remaining data, we computed averaged horizontal EOG waveforms for left- and right-distractor/target trials (see Woodman & Luck, 2003). Participants with residual EOG activity greater than 6.4 μV were excluded, which means that the residual eye movements in the remaining participants averaged less than ±0.4°, with a propagated voltage of less than 0.2 μV at the posterior scalp sites (Lins, Picton, Berg, & Scherg, 1993).

Averaged ERP waveforms were computed with a 500-ms epoch, beginning 100 ms before stimulus array onset. The N2pc and P_D components were isolated by means of contralateral-minus-ipsilateral difference waves relative to the target-color distractor (see Luck, 2012, for a detailed description and justification of this approach). This makes it possible to eliminate all other ERP components that are not lateralized with respect to the location of the target-color distractor. Amplitude was measured from these difference waves as the mean voltage from 225–275 ms for N2pc and from 275–325 ms for P_D (relative to the mean voltage during the 100-ms prestimulus baseline period) at the P7 and P8 electrode sites (because both the N2pc and P_D are large at these sites). The time windows were based on a previous study using this paradigm in healthy young adults (Sawaki et al., 2012), but shifted by approximately 25 ms because N2pc latency in a comparable sample of patients and control subjects (Luck et al., 2006) was delayed relative to the latencies observed in a similar paradigm with healthy young adults (Woodman & Luck, 2003).

To ensure that the results were not biased by our choice of measurement windows, we confirmed all amplitude analyses using signed amplitude measures that do not depend on precisely defined measurement windows, combined with nonparametric permutation tests of statistical significance that require no assumptions about normality, equal variances, and so forth (Sawaki et al., 2012; Sawaki & Luck, 2013; see Luck, 2014, chap. 9). The pattern of statistical significance was identical to that obtained with the conventional approach (see the online supplemental material). In addition, all correlational analyses used the Spearman rho rank-order correlation coefficient, which is important for minimizing the effects of outliers.

Results

Behavior

Table 2 summarizes the behavioral results. Mean RT for target-present responses was significantly longer in PSZ than in HCS, $t(38) = 3.4$, $p = .002$, $d = 1.10$, reflecting the slowing of manual responses that is typically observed in schizophrenia (Nuechterlein, 1977). There was no significant difference in mean hit rate for target-present responses between the groups, $t(38) = 1.2$, $p = .243$.

Additional analyses were conducted for the target-absent trials (see Table 2). A target-color distractor was present on some of these trials (target-color distractor trials) but not on others (target-color absent trials). In both groups, mean RT was slightly longer when the target-color distractor was present than when it was absent. In addition, mean RT was substantially greater in PSZ than

Table 2
Behavioral Results (Mean ± Standard Deviation)

Variable	HCS	PSZ
Reaction time (ms)		
Target-present response[a]	520 ± 88	627 ± 111
Target-absent response		
Target-color distractor[a]	408 ± 97	523 ± 109
Target-color absent[a]	391 ± 90	511 ± 110
Correct response rate (%)		
Target-present response	83.3 ± 13.8	78.4 ± 12.7
Target-absent response		
Target-color distractor	98.3 ± 3.9	95.2 ± 6.6
Target-color absent	98.3 ± 4.1	95.4 ± 6.9

Note. HCS = healthy control subjects; PSZ = people with schizophrenia.
[a] Significant difference between HCS and PSZ.

in HCS. A two-way analysis of variance (ANOVA) with factors of group and presence or absence of a target-color distractor confirmed these observations, yielding significant main effects of group, $F(1, 38) = 13.3$, $p = .001$, and of the presence or absence of a target-color distractor, $F(1, 38) = 38.3$, $p < .001$. There was no significant interaction, $F(1, 38) = 1.2$, $p = .282$. An analogous two-way ANOVA for the mean correct rejection rate on target-absent trials yielded no significant main effects or interaction. Note that this task was not designed to provide a sensitive behavioral measure of distraction and, accordingly, the distraction effects were too small to reliably assess between-groups differences in distractibility.

Event-Related Potentials

Figure 2A shows the ERP waveforms on trials with a target-color distractor from electrodes over the visual cortex contralateral and ipsilateral to the target-color distractor (P7 and P8). Figure 2B shows contralateral-minus-ipsilateral difference waveforms that isolate the N2pc and P_D components from the rest of the ERP activity. In HCS, arrays containing a target-color distractor elicited a small (and statistically nonsignificant; see below) N2pc component (a negative deflection in the difference wave, peaking at approximately 220 ms poststimulus) followed by a larger P_D component (a positive deflection in the difference wave, peaking at approximately 300-ms poststimulus). This is the same pattern that has been observed in healthy young adults (Sawaki et al., 2012). In PSZ, however, no P_D component was visible, and the waveform was dominated by a large N2pc component from approximately 175 to 400 ms. Thus, whereas HCS actively suppressed the target-color distractor (as indicated by the P_D component), PSZ exhibited a strong and long-lasting capture of attention (large N2pc with no P_D). Topographic maps of the P_D and N2pc components are plotted in Figure 2C. Figure 2D shows the group means and single-subject mean amplitude values from the N2pc time-window (225–275 ms) and the P_D time window (275–325 ms) in the contralateral-minus-ipsilateral difference waves. Because capture by target-color distractors was measured relative to a concomitant nontarget color distractor presented in the opposite hemifield, this phenomenon was specific to task-irrelevant stimuli matching the internal goal template. Therefore, it does not reflect

nonspecific distractibility in PSZ, but instead reflects greater focusing of spatial attention onto items that match the target template.

To assess the statistical significance of these ERP effects, we measured the mean voltage from 225–275 ms (N2pc) and from 275–325 ms (P_D) in the contralateral-minus-ipsilateral difference waves. One-sample t tests comparing the mean voltage during the N2pc time window against zero indicated that a reliable N2pc was present in PSZ, $t(19) = -3.4$, $p = .003$, but not in HCS, $t(19) = -0.4$. A two-sample t test indicated that the voltage in this window was significantly more negative in PSZ than in HCS, $t(38) = 2.3$, $p = .027$, $d = 0.75$. In the P_D latency range, in contrast, one-sample t tests indicated that a significant positive voltage was present in HCS, $t(19) = 2.6$, $p = .016$, whereas in PSZ the voltage in this period was negative and not significantly different from zero, $t(19) = -1.6$, $p = .120$. A two-sample t test comparing the groups indicated that the voltage during the P_D time window differed significantly between HCS and PSZ, $t(38) = 2.9$, $p = .007$, $d = 0.94$. Thus, PSZ exhibited a significant N2pc but not a significant P_D, whereas HCS exhibited a significant P_D but not a significant N2pc. Note that because the N2pc was significantly larger in PSZ than in HCS, the present results cannot be explained by poorer task compliance, poorer signal quality, and so forth These patterns of significance were verified using nonparametric methods that are relatively insensitive to the specific measurement windows and outliers and do not require any assumptions of normality, equal variances, and so forth (see the online supplemental material).

Correlations With Working Memory Capacity and IQ

As in previous research, visual working memory capacity was significantly reduced in PSZ ($M = 2.44$, $SD = 0.66$) compared to HCS ($M = 2.99$, $SD = 0.41$), $t(34) = 3.0$, $p = .005$, $d = 0.97$.[1] To examine whether the extent of attending to versus suppressing the target-color distractor was associated with reductions in visual working memory capacity, we calculated the correlation between working memory capacity and mean ERP amplitude in the P_D time window (mean voltage from 275–325 ms in the contralateral-minus-ipsilateral difference waves). A modest positive correlation was found in PSZ, but it did not reach statistical significance, $\rho(17) = 0.322$, $p = .179$. This correlation was near zero (and slightly negative) in HCS, $\rho(15) = -0.128$, $p = .625$. Similar correlations were observed between P_D amplitude and IQ scores, PSZ: $\rho(16) = 0.381$, $p = .118$; HCS: $\rho(18) = -0.365$, $p = .113$, which probably reflects the fact that working memory capacity was correlated with IQ, especially in PSZ, PSZ: $\rho(16) = 0.798$, $p < .001$; HCS: $\rho(15) = 0.338$, $p = .185$.

No significant correlations were found between any of the symptom measures (SANS total score and BPRS factor scores) and mean ERP amplitude in the P_D time window.

Exploratory Analyses of Later ERP Activity

The data processing and analyses described so far were conducted using a priori parameters based on our previous study of

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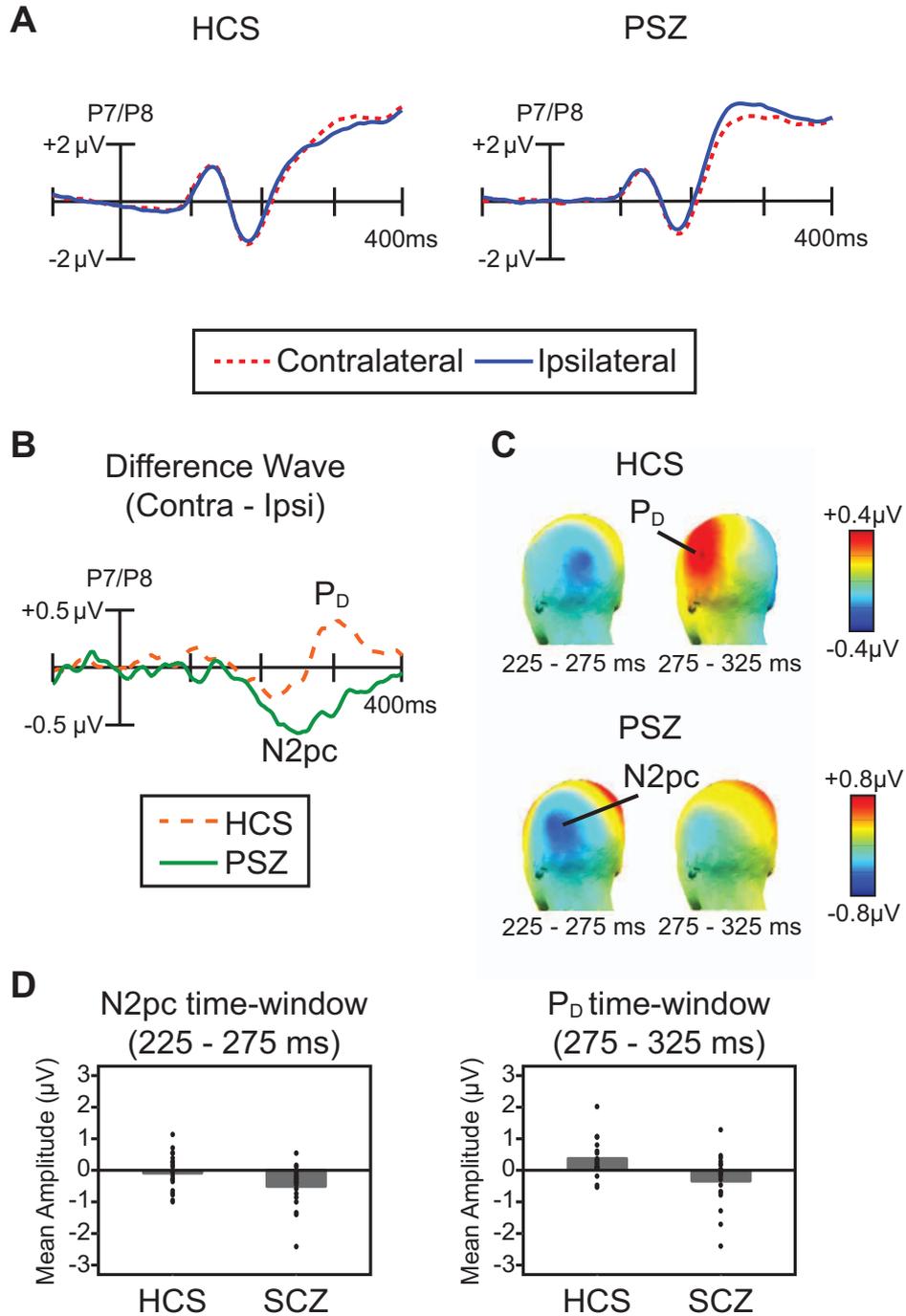[1] Working memory capacity scores were missing for one PSZ and three HCS.

Figure 2. Event-related potential results for target-color distractors. (A) Grand average waveforms from healthy control subjects (HCS) and people with schizophrenia (PSZ) at contralateral versus ipsilateral electrode sites relative to the target-color distractor side (averaged over P7 and P8). (B) Grand average difference waveforms obtained by subtracting the ipsilateral waveforms from the contralateral waveforms (average over P7 and P8). (C) Topographic map of the distractor positivity (P_D) component from HCS (275–325 ms) and the N2-posterior-contralateral (N2pc) component from PSZ (225–275 ms). The data are arranged so that the left and right sides of the head represent contralateral and ipsilateral electrode sites, respectively. (D) Mean amplitude from the N2pc time window (225–275 ms) and the P_D time window (275–325 ms) in the contralateral-minus-ipsilateral difference waves for HCS and PSZ. Each dot represents an individual participant. See the online article for the color version of this figure.

healthy young adults (Sawaki et al., 2012). This approach has the advantage of reducing "experimenter degrees of freedom" and the likelihood that the results were biased by the choice of analysis parameters (Simmons, Nelson, & Simonsohn, 2011). However, an important question that cannot be answered by our previous analyses is whether PSZ have a P_D component that is so delayed that it falls outside our ERP epoch. We therefore reaveraged the data with a longer epoch (-100 to 600 ms).

As shown in Figures 3A and 3B, a P_D-like effect was indeed present from approximately 400–450 ms in the grand average waveforms for PSZ but not for HCS. This effect was not statistically significant for either group when measured as the mean amplitude from 400–450 ms, HCS: $t(19) = 0.1$, $p = .931$; SCZ: $t(19) = 1.1$, $p = .302$, but the contralateral-minus-ipsilateral voltage difference in this time range was significantly correlated with visual working memory capacity in PSZ, $\rho(17) = 0.638$, $p = .003$, but not in HCS, $\rho(15) = 0.098$, $p = .708$ (Fisher's z transformation test for difference in correlation: $z = 1.79$, $p = .074$; see scatterplot in Figure 3C). The voltage was also significantly correlated with IQ in PSZ, $\rho(16) = 0.620$, $p = .006$, but not in HCS, $\rho(18) = -0.199$, $p = .401$; Fisher's z transformation test for difference in correlation: $z = 2.62$, $p = .009$). In other words, PSZ who exhibited a more positive (P_D like) voltage in this late time range had higher working memory capacity and higher IQ scores than PSZ who exhibited a more negative (N2pc like) voltage, which is the same pattern of correlation obtained for the earlier P_D time window. Although exploratory, these results suggest that at least a subset of PSZ are eventually able to inhibit the target-color distractor after focusing attention on it, and that this ability is associated with higher working memory capacity and higher IQ.

Medication Effects

To examine the possible effects of medication on the observed ERP results, we tested the correlation between medication dosage (chlorpromazine equivalent, calculated according to Andreasen et al., 2010) and mean amplitude in the N2pc and P_D time windows (N2pc: 225–275 ms; P_D: 275–325 ms) and in the late time window from the exploratory analysis (400–450 ms). No significant correlations were obtained: 225–275 ms: $\rho(17) = -0.147$, $p = .547$; 275–325 ms: $\rho(17) = -0.156$, $p = .523$; 400–450 ms: $\rho(17) = -0.340$, $p = .155$; thus, it is unlikely that the present effects are primarily a consequence of antipsychotic medication usage.

Discussion

These results provide evidence that PSZ exhibit an aberrant focusing of attention onto objects that partially match task goals. In other words, objects that partially match task goal representation are more potent in attracting attention in PSZ than in HCS. This result is counterintuitive given the evidence that schizophrenia involves impairments in goal maintenance (Barch & Smith, 2008; Cohen et al., 1999; Servan-Schreiber et al., 1996). If PSZ had failed to maintain the goal of detecting the target color, a distractor matching this color would have been less prone to capturing attention and producing an N2pc. Moreover, if PSZ had remembered the relevant color but failed to remember which location was

relevant, they would have made more errors (false alarms) when the target-color distractor was present than when it was absent, but accuracy was >95% correct on these trials. However, the present task was designed to make goal maintenance trivially easy, and under these conditions objects that contain goal-related features were more likely to attract attention in PSZ than in HCS. Thus, although PSZ may fail to maintain goal representations when goal maintenance is challenged, they are more prone to focusing attention onto stimuli that share features with the intended target when they are able to maintain goal representations.

The present results cannot be explained by a general impairment in filtering distractors. First, the target-color distractor and the neutral-color distractor on the opposite side of the display had equivalent bottom-up salience, and yet PSZ exhibited a large N2pc component to the target-color distractor. Thus, attention was attracted specifically to items that matched the goal-relevant color rather than being attracted equally to both distractors. Second, several previous studies have shown that PSZ are capable of normal top-down target selection and distractor filtering when the distractors do not share target features. For example, physically salient distractors presented simultaneously with or immediately after a set of to-be-remembered objects do not cause substantial working memory impairments in PSZ (Erickson et al., 2014, 2015). Similarly, physically salient "color singleton" distractors cause no more interference with visual search performance in PSZ than in HCS (Leonard, Robinson, Hahn, Gold, & Luck, 2014). In contrast, the present ERP results and two previous behavioral studies (Luck et al., 2014; Mayer et al., 2012) indicate that PSZ exhibit exaggerated distraction by items that partially match active target representations.

Furthermore, the present results are not easily explained by a general impairment in focusing attention onto the central, task-relevant location. First, many previous studies have shown that PSZ can focus their spatial attention just as well as can HCS; if anything, PSZ focus their attention more narrowly than do HCS (Elshaikh, Sponheim, Chafee, & MacDonald, 2015; Hahn, Robinson, et al., 2012; Spencer et al., 2011). Second, if HCS had focused their attention so narrowly that the target-color distractor was outside the "spotlight" of attention, they would not have needed to actively suppress this distractor and would not have shown a P_D. In other words, for the target-color distractor to elicit a P_D in HCS, it must have fallen within the spatial focus of attention. Indeed, previous research shows that healthy adults do not exhibit a P_D when attention is sufficiently narrowly focused (Sawaki & Luck, 2010). Thus, the fact that the target-color distractor elicited a P_D in HCS and an N2pc in PSZ means that this distractor was within the spotlight of attention for both groups. The difference between groups was that attention was drawn to the target-color distractor in PSZ whereas this distractor was activity suppressed by HCS.

Given that attention was captured by target-color distractors in PSZ, one might wonder why PSZ did not show a large RT difference between trials with and without a target-color distractor (on target-absent trials). A likely explanation is that, because the target was absent on 90% of trials, the target-absent response was so prepotent that it was not sensitive to shifts of attention. In other words, even if attention was captured by the target-color distractor, the nontarget response was already programmed and ready to go, making it relatively impervious to a shift of attention. Thus, the
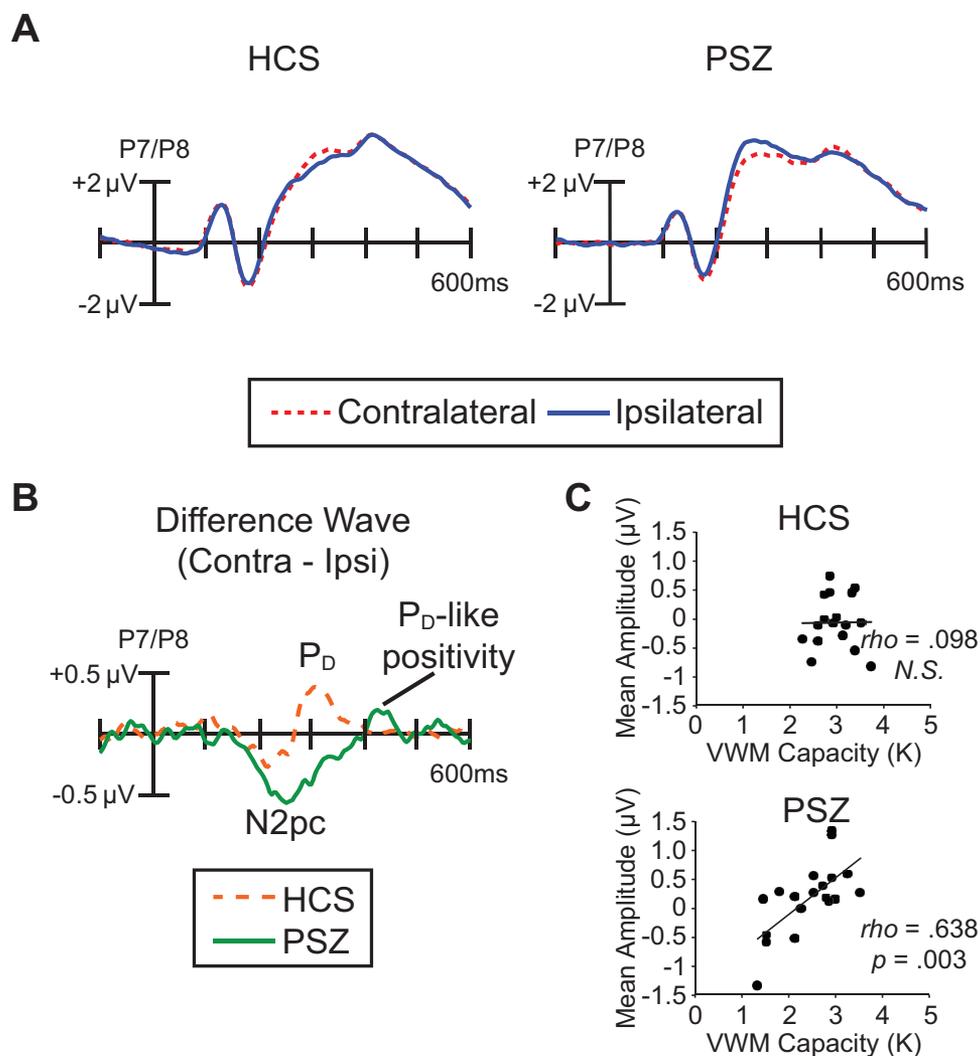
A

HCS

PSZ

P7/P8
+2 μV

-2 μV

600ms

P7/P8
+2 μV

-2 μV

600ms

----- Contralateral — Ipsilateral

B

Difference Wave
(Contra - Ipsi)

P_D-like
positivity

P7/P8
+0.5 μV

P_D

-0.5 μV

600ms

N2pc

----- HCS
— PSZ

C

HCS

Mean Amplitude (μV)
1.5
1.0
0.5
0
-0.5
-1
-1.5
0 1 2 3 4 5
VWM Capacity (K)

rho = .098
N.S.

PSZ

Mean Amplitude (μV)
1.5
1.0
0.5
0
-0.5
-1
-1.5
0 1 2 3 4 5
VWM Capacity (K)

rho = .638
p = .003

Figure 3. Event-related potential results for target-color distractors with a longer epoch. (A) Grand average waveforms from healthy control subjects (HCS) and people with schizophrenia (PSZ) at contralateral versus ipsilateral electrode sites relative to the target-color distractor side (averaged over P7 and P8). (B) Grand average difference waveforms obtained by subtracting the ipsilateral (Ipsi) waveforms from the contralateral (Contra) waveforms (average over P7 and P8). (C) Scatterplot showing each participant's visual working memory (VWM) capacity (K) against the mean amplitude from 400–450 ms in the contralateral-minus-ipsilateral difference waves. N2pc = N2-posterior-contralateral; P_D = distractor positivity; N.S. = not significant. See the online article for the color version of this figure.

present paradigm was not designed to provide a sensitive behavioral measure of the focusing of attention onto target-color distractors. However, as mentioned earlier, two previous studies have found behavioral evidence of exaggerated attention to nontarget items that match a task-relevant color (Luck et al., 2014; Mayer et al., 2012). The present results extend those prior findings by providing converging evidence from a very different experimental task that used electrophysiological rather than behavioral measures and provided a continual reminder of the goal.

The underlying mechanism responsible for the aberrant focusing of attention onto objects that partially match task goals is not yet known. However, we speculate that this finding is related to the hyperfocusing hypothesis, which proposes that PSZ tend to focus their processing resources more intensely but more narrowly than HCS as a result of disrupted attractor dynamics that tend to create deeper basins of attraction and produce exaggerated winner-take-all processing (Luck et al., 2014). This hyperfocusing can explain several aspects of cognitive dysfunctions in schizophrenia. For example, previous studies have shown that PSZ are impaired at storing multiple visual objects in working memory (Johnson et al., 2013) and at distributing attention across multiple spatial locations (Gray et al., 2014; Hahn, Robinson, et al., 2012), but under some conditions they focus attention more strongly than HCS on cued stimuli (Hahn, Hollingworth, et al., 2012; Spencer et al., 2011). In

addition, when asked to store one object in working memory and ignore another object, PSZ actually show greater maintenance-related neural activity than HCS during the delay period (Leonard, Kaiser, et al., 2013), consistent with more intense working memory representations when resources can be focused on a single object. Thus, the hyperfocusing hypothesis predicts reduced working memory storage capacity in PSZ because resources are focused more intensely on a smaller number of representations.

In the present paradigm, the hyperfocusing hypothesis predicts that PSZ will maintain a more intense representation of the task set (i.e., the target color) than will HCS. As a result, a stimulus that matches this representation will be more likely to attract attention, even if that stimulus is not a target. This could explain the finding that attention was captured by the target-color distractor in PSZ but not in HCS. Moreover, the finding that increased attentional allocation to the target-color distractor was associated with lower working memory capacity on PSZ, at least during the 400- to 450-ms time window, is consistent with the hypothesis that both the aberrant attention and decreased working memory exhibited by PSZ are related to a common underlying mechanism: PSZ tend to focus their processing resources more narrowly but more intensely than HCS. Thus, PSZ who exhibit more aberrant focusing of attention in the present visual target detection task would also be expected to hyperfocus on a smaller number of representations in working memory, leading to reduced storage capacity (and possibly also reduced IQ, which is strongly influenced by working memory capacity).

There are some limitations of the present study. First, the N2pc and P_D components have opposite polarities and similar scalp distributions, and thus the average ERP waveforms reflect the relative balance of these components. Therefore, it is possible, in principle, that the P_D was present in PSZ but was not visible due to a very large overlapping large N2pc. Even if that were true, however, the results would indicate that the balance of attraction and suppression was much more weighted toward attraction of attention by the target-color distractor in PSZ than in HCS. A second limitation is the fact that we cannot rule out a contribution of medications in the PSZ. There was no significant correlation between chlorpromazine equivalent dosage and our ERP measure of distraction, but additional research would be needed to definitively rule out a role of medication. Finally, our sample size was modest, which is especially important when considering how the neural activity is correlated with behavioral measures of cognition and with symptoms. It would be useful for future research with larger sample sizes to explore the pattern of correlation in more detail.

In summary, the present results provide electrophysiological evidence that PSZ focus attention more intensely than HCS on objects that partially match task goals, consistent with prior behavioral evidence. PSZ thus face two problems associated with goals: They may have difficulty maintaining appropriate goals under conditions that challenge goal maintenance, and when they successfully maintain a goal they may hyperfocus on it and be distracted by irrelevant information that partially matches the goal. Additional research is needed to determine whether these two problems reflect an abnormality in the same or different neural circuits.

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