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Increased influence of a previously attended feature in people with schizophrenia

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Abstract

Everyday functioning requires the appropriate allocation of visual attention, which is achieved through multiple mechanisms of attentional guidance. Traditional theories have focused on top-down and bottom-up factors, but implicit learning from recent experience ("selection history") also has a substantial impact on attentional allocation. The present experiment examined the influence of intertrial priming on attentional guidance in people with schizophrenia and matched control subjects. Participants searched for a color popout target, which switched randomly between a red target among blue distractors and a blue target among red distractors. We found that performance on the current trial was more influenced by the previous-trial target color in people with schizophrenia than in control subjects. Moreover, this implicit priming effect was greater in individuals with lower working memory capacity (as measured in a separate task). These results suggest that intertrial priming has an exaggerated impact on attentional guidance in people with schizophrenia and that this is associated with other aspects of impaired cognition. Overall, these results are consistent with the *hyperfocusing hypothesis*, which proposes that a single underlying attentional abnormality may explain a range of atypical effects across perception, attention, and cognition in schizophrenia.

General Scientific Summary:

Attentional allocation is influenced not only by current goals and the present visual scene, but also by the recent history of selection. The current results indicate that people with schizophrenia show an increased influence of this history. Moreover, the magnitude of this influence relates to individual differences in working memory, consistent with a common mechanism.

Keywords

priming; attention; schizophrenia

Understanding the nature of cognitive impairment in schizophrenia has proven challenging because the underlying mechanisms that contribute are complex and hard to fully

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encapsulate within a single psychological construct. The construct of attention, for example, has long been thought to be impaired in schizophrenia (e.g., Nuechterlein & Dawson, 1984), but is inexorably involved in many aspects of cognitive functioning, including perception, memory, and executive functioning. Recently, we proposed a *hyperfocusing hypothesis* to explain how an attentional abnormality can explain atypical functioning across a range of cognitive domains, including perception and working memory (Luck, Hahn, Leonard, & Gold, 2019).

According to the hyperfocusing hypothesis, people with schizophrenia (PSZ) vary from healthy control subjects (HCS) in that their processing resources are aberrantly focused on a limited number of representations with greater intensity. This manifests as an atypically narrow spatial window of attention (Elahipanah, Christensen, & Reingold, 2010; Leonard, Robinson, Hahn, Luck, & Gold, 2017), even when broader spreading of resources would be more optimal (Elahipanah, Christensen, & Reingold, 2011; Gray et al., 2014; Hahn et al., 2012). Hyperfocusing is also a natural explanation for the finding of reduced working memory capacity in PSZ (e.g., Johnson et al., 2013), as processing resources would be focused more intensely on a smaller number of stored objects. Indeed, several studies have shown that PSZ devote greater resources than HCS when asked to focus on a single visual working memory representation, as measured by event-related potentials (Leonard et al., 2013) and functional magnetic resonance imaging (Hahn, Robinson, Leonard, Luck, & Gold, 2018; Manoach, 2003).

Previous research has shown that attention is attracted to perceptual inputs that match the current contents of working memory (e.g., Carlisle, Arita, Pardo, & Woodman, 2011; Desimone & Duncan, 1995; Woodman & Arita, 2011). Therefore, more intense working memory representations in PSZ should lead to greater processing of objects that match the contents of memory. Indeed, recent research has shown that information being held in working memory has an exaggerated influence on the guidance of attention in PSZ (Luck et al., 2014; Mayer, Fukuda, Vogel, & Park, 2012; Sawaki et al., 2017).

Attention can also be guided by implicit memory representations of recent experiences, which is often studied in the context of intertrial priming. Specifically, search performance is improved when a target feature or dimension repeats from one trial to the next (Found & Muller, 1996; Leonard & Egeth, 2008; Maljkovic & Nakayama, 1994). This intertrial priming is based on implicit rather than explicit memory (Jiang, Shupe, Swallow, & Tan, 2016; Maljkovic & Nakayama, 1996), is independent of top-down, goal-related guidance (Leonard & Egeth, 2008), and depends on the previous selection of a task-relevant target (Goolsby & Suzuki, 2001; Kristjansson, Saevarsson, & Driver, 2013). Such intertrial priming is a type of *selection history* effect, which has been the focus of much research in the basic attentional literature since it extends beyond the traditional dichotomy of top-down and bottom-up guidance factors (Anderson, 2017; Awh, Belopolsky, & Theeuwes, 2012). If PSZ focus more intensely on a visual search target than do HCS, then this might lead to a stronger implicit memory and therefore larger effects of priming on the next search trial.

Implicit priming has often been examined in PSZ in the context of procedural learning (Gras-Vincendon et al., 1994), semantic content (Spitzer, Braun, Hermle, & Maier, 1993),

and language production (Salzinger, Pisoni, Portnoy, & Feldman, 1970), with results suggesting either normal or enhanced priming effects. However research examining intertrial priming effects in visual search have been limited. Ravizza, Robertson, Carter, Nordahl, and Salo (2007) did find that PSZ were more slowed than HCS when the target identity switched between trials, although whether this represented a slowing in the speed of attentional allocation is unclear because repetition of the target identity was confounded with repetition of the motor response in their task.

To test the prediction of greater priming in PSZ than in HCS in the context of visual attention, we used the well-studied *priming-of-popout* paradigm (Maljkovic & Nakayama, 1994), in which participants searched for a unique color in a field of homogenous distractors (i.e., a blue target within a field of red distractors or a red target within a field of blue distractors; see Figure 1A). The target and distractor colors varied unpredictably from trial to trial, and the target was defined by virtue of being a popout rather than being defined by a specific color. Response times in this paradigm are typically faster when the color of the target on the current trial happens to be the same as the color of the target on the previous trial (Leonard & Egeth, 2008; Maljkovic & Nakayama, 1994). The hyperfocusing hypothesis predicts that the increased intensity of selection on one trial will lead to a larger influence of the features of that target on attentional guidance in the next trial. Thus, we hypothesized that the intertrial priming effect would be greater in PSZ than in HCS. Given that hyperfocusing is also proposed to underlie reduced working memory capacity (Luck et al., 2019), we further predicted that working memory capacity would be negatively correlated with intertrial priming magnitude.

Methods

Participants

Forty-five PSZ and 37 HCS took part in this experiment. In total, 7 PSZ were excluded due to response omission on more than 25% of trials (1 participant), performance accuracy below 75% (5 participants), or both (1 participant). The clinical description provided below refers to the remaining 38 PSZ (29 diagnosed with schizophrenia and 9 with schizoaffective disorder) and 37 HCS included in the analyses.

Diagnosis was based on standard operational criteria in the Diagnostic and Statistical Manual of Mental Disorders, fourth edition, text revision (DSM–IV–TR). A best estimate approach was used to establish diagnosis by combining material from medical records, collateral informants (when available), and the results of the Structured Clinical Interview for DSM–IV–TR Axis-I disorders (SCID-I). Final diagnosis was reached at a consensus conference. All in the PSZ group were clinically stable outpatients receiving antipsychotic medications, at the same dose, for at least 4 weeks before participation. Medication dosages were converted into chlorpromazine equivalents using the methods described in Andreasen, Pressler, Nopoulos, Miller, and Ho (2010).

No significant differences were found between groups in age, race, gender, parental education, or handedness. As is typically found, years of education was lower for PSZ than for HCS, consistent with the disorder limiting education attainment. Demographic

information and statistical comparisons are provided in Table 1. All participants were free of other medical or neurologic comorbidity that might influence test performance, including substance abuse or dependence within the last 12 months. This protocol (HP-00054557) was approved by the Institutional Review Board at the University of Maryland, Baltimore. All participants gave written informed consent before study participation.

Stimuli

Stimuli were presented on an LCD monitor (43.5 cm wide), with participants seated at a viewing distance of 100 cm. A light gray background was presented throughout the search task. For each trial, a fixation cross appeared for 300 ms followed by a search display. The duration of the search display was 750 ms, followed by a 750-ms blank screen. Responses were allowed during this 1500-ms time period. The screen remained blank for another 750 ms beyond the response window, after which the fixation appeared for the next trial. Timing was fixed to ensure that between-subject differences in reaction time would not impact the intertrial interval, which could influence priming magnitude.

As in Maljkovic and Nakayama (1994), stimuli were colored diamonds (rotated 0.75° squares) which were each missing a 0.15° chip at either the top or bottom (see Figure 1A). The target was always a singleton: either a blue (10.8 cd/m^2,CIE x:0.15, y:0.03) target diamond among 5 red (15.2 cd/m^2,CIE x:0.71, y:0.27) distractors or a red target diamond among 5 blue distractors. On each trial, the diamonds were evenly distributed on an imaginary circle around the fixation cross with an eccentricity of 3°. The task was to report the location of the missing chip on the uniquely colored object within each display. The chip was randomly located on the top or bottom of each shape, making the response uncorrelated with the color of the current-trial target. In other words, repetition of the target color from one trial to the next was uncorrelated with whether or not the same response was required from one trial to the next. This makes it possible to distinguish between attentional priming and response priming.

All participants except 2 of the 38 PSZ also performed a *change localization* task. This task provides a reliable measure of working memory capacity that is strongly correlated with broader measures of cognitive ability (Johnson et al., 2013). On each trial, 4 colored squares (0.7°) were presented for 100 ms, followed by a 900-ms blank delay. The squares were arranged on an imaginary circle (3° radius), with at least 2.33° separation between them. After the delay, all squares reappeared, but on every trial one square reappeared in a different color, and the participant's task was to click on the square that had changed color. As in Johnson et al. (2013), working memory capacity was estimated by multiplying the proportion correct by the number of objects to be maintained (4).

Design & Procedure

For the visual search task, participants first completed a block of 10 practice trials, which was repeated if any confusion remained. Then, each participant completed a single block of 288 experimental trials (12 repetitions of 6 target locations x 2 response types x 2 color mappings). The experiment took approximately 30 minutes, with short breaks every 72 trials. Participants were instructed to find the diamond that was a different color than the rest

and make a button- press response to report the location of the missing chip on this target. Responses were made using the top and bottom trigger buttons on a Logitech gamepad to indicate a missing chip on the top or bottom of the target, respectively. The experimenter emphasized that participants should respond as quickly as possible while still being correct most of the time.

The change localization task was performed in a separate session. Each participant completed 60 trials. Accuracy rather than speed was stressed in this task.

Visual Search Analysis

On a small percentage of trials, no response was made during the 1500-ms response window (HCS:1.0%; PSZ:1.9%), and these trials were excluded from further analysis. Behavioral performance was assessed through accuracy (proportion correct) and through reaction time (RT) on correct trials. Intertrial effects were calculated by examining current-trial performance on the basis of whether the color of the target repeated or switched from the previous trial (N-1). Note that the trials were in random order, so repetitions and switches occurred unpredictably and with equal probability. The first trial of the experiment, the first trial after each break, and the first trial after an error were excluded from analysis. The primary statistical analyses used ANOVA with trial type (repeat, switch) and group (HCS, PSZ) as factors.

Results

Feature priming effects

Accuracy was high overall, with a mean accuracy of over 90% correct in both groups across all conditions. Figure 1B shows accuracy as a function of whether the target color mapping switched or repeated. Both groups were more accurate for repeat trials than for switch trials ($F(1,73) = 30.37$, $p < 0.001$, $\eta_p^2 = 0.29$, 90% CI[0.15 0.42]), and HCS were more accurate than PSZ overall ($F(1,73) = 4.67$, $p = 0.03$, $\eta_p^2 = 0.06$, 90% CI[0.00 0.16]). The effect of repeat/switch was numerically larger in PSZ than in HCS, but the interaction between group and repeat/switch was not significant ($F(1,73) = 1.45$, $p = 0.23$, $\eta_p^2 = 0.02$, 90% CI[0.00 0.10]). Because accuracy was near ceiling, our primary analyses focused on RT (as in most priming-of-popout studies).

RT for correct trials is plotted in Figure 1C. As in previous priming-of-popout studies, RT was significantly faster when the target/distractor color mapping was repeated from the previous trial compared to when the mapping switched ($F(1,73) = 406.90$, $p < 0.01$, $\eta_p^2 = 0.85$, 90% CI[0.79 0.88]). PSZ were slower overall than HCS ($F(1,73) = 4.28$, $p = 0.04$, $\eta_p^2 = 0.06$, 90% CI[0.00 0.16]). The key finding was that priming from the previous trial (i.e., the difference in RT between repeat and switch trials) was greater in PSZ than in HCS, leading to a statistically significant interaction ($F(1,73) = 5.91$, $p = 0.02$, $\eta_p^2 = 0.08$, 90% CI[0.01 0.18]).

Relationship of feature priming to explicit working memory and level of functioning

Mean working memory capacity in the change localization task was 2.90 for HCS and 2.53 for PSZ ($t(71) = 2.78$, $p < 0.01$, Cohen's $d = 0.66$). This replicates the typical finding of reduced capacity in PSZ compared to HCS (Gold et al., 2010; Gold et al., 2018; Leonard et al., 2013). Of specific interest to this study was the relationship between working memory capacity and the strength of intertrial feature priming within each group of participants. Figure 2 shows a scatterplot of priming magnitude (switch-trial RT minus repeat-trial RT) and working memory capacity. PSZ showed a significant negative relationship, such that individuals with low working memory capacity had stronger feature priming (Spearman's $rho = -0.55$, $p < 0.001$). The relationship between the two variables was not significant for HCS ($rho = -0.21$, $p = 0.20$). Fischer's coefficient showed that this difference in correlation was significant ($z = 1.66$, $p = 0.04$, one-tailed). Note, however, that the range of scores was greater in PSZ than in HCS for both the priming measure and the working memory capacity measure.

In a post-hoc analysis, we examined the relationship of priming to the Level of Function scale and subscales (LOF, Hawk, Carpenter, & Strauss, 1975) that were available for 37 PSZ. There was a significant correlation between priming magnitude and LOF-work, $rho = -0.36$, $p = 0.029$, and a nonsignificant trend with LOF-total, $rho = -0.27$, $p = 0.11$. This relationship was not apparent for LOF-social, $rho = 0.07$, $p = 0.70$.

Control analyses

The hyperfocusing hypothesis led to the prediction that priming-of-popout would be greater in PSZ than in HCS because more intense focusing on the target on one trial would lead to a stronger implicit memory that would carry over to the next trial. An alternative possibility is that PSZ are generally more influenced by recent behavior. This alternative predicts that PSZ would also exhibit greater response priming than HCS, whereas the hyperfocusing hypothesis makes no prediction about response priming. When comparing trials on which the specific button response repeated or switched, both groups showed faster RTs for response repeats compared to response switches (HCS: 718 ms vs 736 ms; PSZ: 771 ms vs. 790 ms), leading to a significant effect of repetition ($F(1,73) = 28.67$, $p < 0.001$, $\eta_p^2 = 0.28$, 90% CI[0.14 0.40]). Overall, PSZ were slower than HCS ($F(1,73) = 4.36$, $p = 0.04$, $\eta_p^2 = 0.06$, 90% CI[0.00 0.16]). However, unlike feature priming, the response priming effect (i.e., the difference between response-repeat and response-switch trials) was nearly identical in PSZ (19 ms) and HCS (18 ms), yielding no significant interaction between trial type and group ($F(1,73) = 0.04$, $p = 0.95$, $\eta_p^2 < 0.001$, 90% CI[0.00 0.03]). Accuracy replicated this pattern, with significant main effects of group ($F(1,73) = 4.39$, $p = 0.04$, $\eta_p^2 = 0.06$, 90% CI[0.00 0.16]) and repetition type ($F(1,73) = 9.74$, $p < 0.01$, $\eta_p^2 = 0.12$, 90% CI[0.03 0.24]), but no hint of an interaction ($F(1,73) = 0.46$, $p = 0.50$, $\eta_p^2 = 0.01$, 90% CI[0.00 0.07]).

To examine possible medication effects, chlorpromazine equivalents were calculated for each participant in the PSZ group (Andreasen et al., 2010). Target feature priming magnitude did not correlate significantly with chlorpromazine equivalents for RT ($rho = 0.01$, $p = 0.93$) or accuracy ($rho = -0.11$, $p = 0.50$). Symptom measures were obtained (see Table 1) but none correlated with priming (all p's > 0.25).

Discussion

Appropriate daily functioning requires focusing attention on a subset of stimuli to effectively deal with multiple sources of incoming sensory information. In many circumstances, attention is not entirely goal-oriented or stimulus-driven but is instead guided by priming from recent experiences. The current experiment shows that PSZ have an increased amount of intertrial priming for the previously-attended color feature compared to matched HCS. By contrast, response priming was approximately equivalent in PSZ and HCS, suggesting that the exaggerated priming-of-popout effect is specifically related to selective attention. This is consistent with the hyperfocusing hypothesis, which predicts that an increased intensity of attentional selection on one trial will lead to increased priming on the next trial. Indeed, previous work has shown that intertrial priming effects are contingent on the selection of a target on the previous trial (Goolsby & Suzuki, 2001).

These findings cannot be explained by a generalized deficit in PSZ, which would predict poor focusing on the current-trial target color, which would reduce rather than increase priming of popout on the next trial (Kristjansson et al., 2013). This adds to a number of recent findings showing supranormal attention effects in PSZ, as predicted by the hyperfocusing hypothesis (see Luck et al., 2019 for a review). It should be noted that in the current visual search paradigm, this increased priming effect cannot necessarily be interpreted as a benefit or deficit, as it facilitates performance on half of the trials when the target happens to repeat.

The magnitude of feature priming varied considerably between individuals and was linked to individual differences in working memory capacity in PSZ. Working memory capacity has been tied to performance on a wide range of perceptual and cognitive tasks (Conway, Cowan, & Bunting, 2001; Conway, Tuholski, Shisler, & Engle, 1999; Ester, Ho, Brown, & Serences, 2014; Fukuda & Vogel, 2011; Unsworth, Schrock, & Engle, 2004). In PSZ, working memory variation has been related to specific measures of attention (Gray et al., 2014; Johnson et al., 2013) and broad measures of cognitive ability (Johnson et al., 2013). The hyperfocusing hypothesis proposes that the same underlying mechanism produces both reduced working memory capacity and other consequences of aberrant selective attention. The current results are consistent with the idea that a larger influence of selection history is an expression of this putative core cognitive deficit.

This also fits into a predictive coding framework, which suggests that psychopathology is related to improper influences of priors over current sensory input (Corlett, Frith, & Fletcher, 2009; Powers, Mathys, & Corlett, 2017). An increased tendency to attend to a previously-attended feature could be framed as an increased influence of priors and also fits results that have been discussed in terms of perseveration (Crider, 1997; Goldberg, Weinberger, Berman, Pliskin, & Podd, 1987).

It is important to note some limitations of this study. First, it is unknown if the present effects would generalize to other attention-guiding features (e.g., shape) or other tasks. Second, we examined chronic, medicated outpatients. Nonetheless, the present results

illustrate another example of how hyperfocusing can explain abnormalities across perception, attention, and cognition in schizophrenia.

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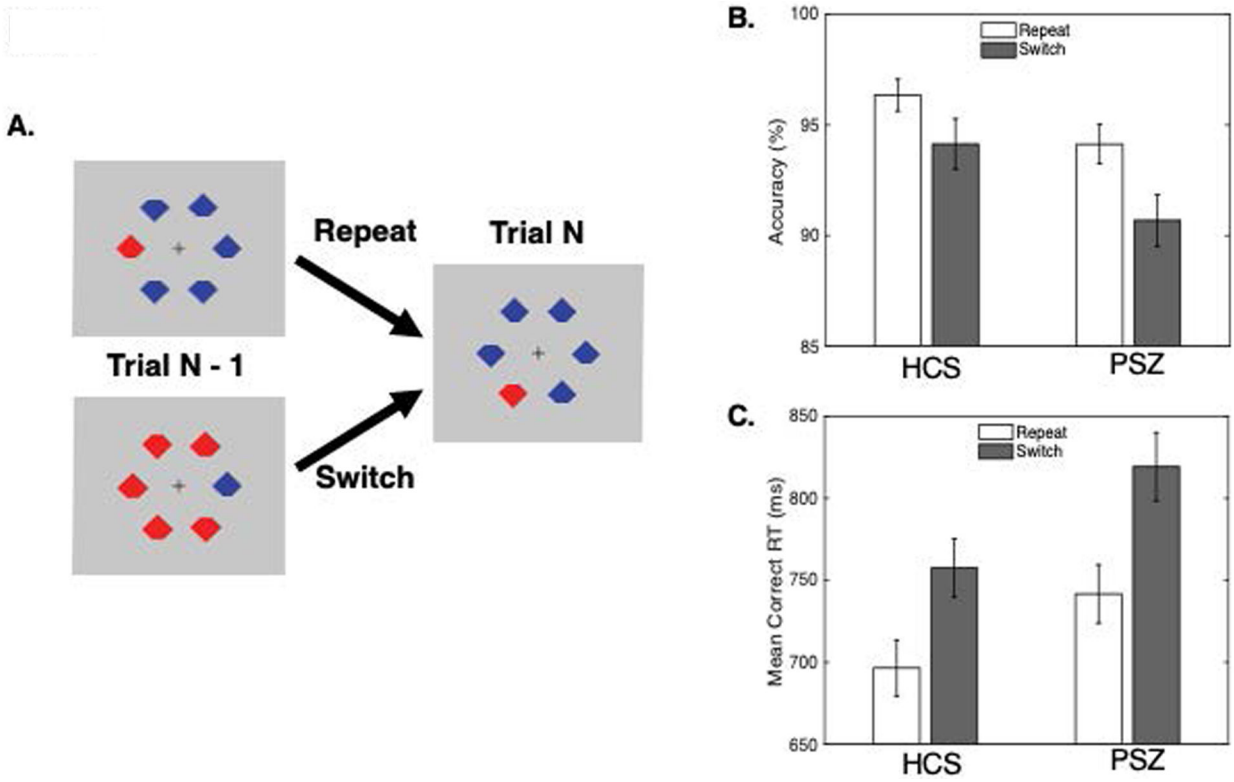

Figure 1.

A) Example of visual search displays and intertrial contingencies that define the critical conditions. The task is to find the uniquely-colored diamond and report whether a chip is missing from the top or bottom. Trial N is classified as a repeat trial if the target and distractor colors are the same as on trial N-1, and as a switch trial if the colors were reversed relative to trial N-1. B) Mean response accuracy as a function of condition (repeat, switch) and group (HCS, PSZ). Error bars represent the standard error of the mean. C) Mean reaction time on correct trials.

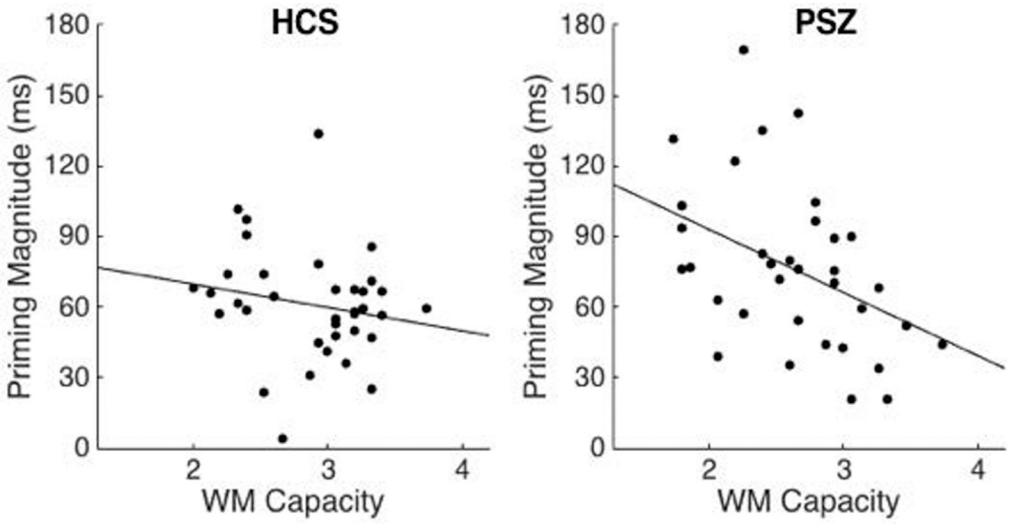

Figure 2.

Scatterplot showing individual feature priming magnitude and working memory capacity measures. Lines show least-squares best fit. A) HCS, Spearman's rho = −0.21, p = 0.2. B) PSZ, Spearman's rho = −0.55, p < 0.01.

Table 1.

Demographic information for sample.

	HCS N=37	PSZ N=38	Stats
Age	37.76±10.88	36.95±11.13	t(73) = 0.32, p = 0.75
Education (yrs)	15.49±2.06	12.92±2.31	t(73) = 5.06, p < 0.01
Parental Education (yrs)[1]	14.26±2.70	13.80±2.86	t(73) = 0.71 p = 0.48
Male/Female (M:F)	25:12	26:12	$\chi^2(1) < 0.01$, p = 0.94
Race (AA:W:O)	13:22:2	12:24:2	$\chi^2(2) = 0.11$, p = 0.95
Symptom and Medication Measures for PSZ[2]	BPRS-Pos: 1.89±0.94, BPRS-Neg: 1.59±0.56, BPRS-Dis: 1.19±0.26 BPRS-Tot: 31.3±7.89 LOF-Total: 20.6±6.1, LOF-Social: 4.89±2.45, LOF-Work: 2.48±2.77 Chlorpromazine Equivalent: 455.5, SD = 283.2		

[1] Parental education is the average years of mother and father when both are available. Two participants in the HCS group were only able to report education information about a single parent.

[2] BPRS scores (Overall & Gorham, 1962) were calculated with the 3-factor model (McMahon et al., 2002). Symptom and LOF ratings were not available for 1 PSZ.