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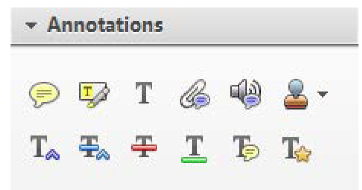

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Self-Reported Perceptual Aberrations in Psychosis Map to Event-Related Potentials and Semantic Appraisals of Objects

AQ: au

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Psychotic disorders have been associated with visual deficits and deviant semantic processing, making it unclear whether object detection abnormalities in psychosis originate from low-level or higher-order visual processes. The current study investigated how high-level visual processing is affected in psychosis by presenting object stimuli with equivalent low-level visual features. Outpatients with affective and nonaffective psychotic disorders, first-degree biological relatives, and psychiatrically unaffected individuals (N = 130) completed the fragmented ambiguous object task to assess recognition of objects in ambiguous stimuli. During the ~~fragmented ambiguous object~~ task, we recorded electroencephalography, quantified event-related potential components (P1, N1, negative closure [N_{CL}], N400), and derived four spatiotemporal event-related potential factors using principal components analysis (PCA). In addition to traditional diagnoses, psychosis was characterized using a dimensional measure of individual differences in self-reported sensory experiences (perceptual absorption) calculated from scales that tap the psychotic domain of the hierarchical structure of psychopathology. Rates of detecting objects within fragmented stimuli failed to differ across diagnostic groups or significantly predict perceptual absorption (p = .057). PCA factors that reflected smaller N1 and larger N_{CL} amplitudes were associated with detecting objects. Exploratory analyses revealed that higher perceptual absorption was associated with reductions in the N400 and a late positive PCA factor. Although early and midlatency brain responses modulate during object detection, late brain responses tied to semantic appraisal of objects are related to perceptual aberrations often reported by individuals with severe psychopathology. Dimensional measures of personality appear sensitive to variation in biological systems relevant to psychotic symptomatology and object perception.

General Scientific Summary

People with mental health diagnoses like schizophrenia often have difficulty correctly discerning objects that are incomplete or obscured. Understanding the behavioral and neural origins of these deficits may help explain extreme perceptual disturbances such as hallucinations, as well as unusual sensory experiences in clinically well people. At the neural level, electroencephalography results suggested that these misinterpretations are due to differences in assigning meaning to objects rather than differences in processing the physical properties of the picture.

Keywords: psychosis, schizophrenia, visual processing, EEG

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This article presents original research that was approved by the Minneapolis Veterans Affairs Health Care System Institutional Review Board (1411M56561) and publicly presented in Julia M. Longnecker's dissertation. Initial results were presented at the 2018 Society for Psychophysiological Research Meeting. A methodological paper using the same sample has been published. However, it did not investigate group personality measures or electroencephalography findings.

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Psychotic disorders are associated with broad perceptual disturbances and impaired performance on experimental paradigms that probe visual perception. Researchers have used visual tasks to consistently reveal abnormal responses in schizophrenia related to detecting fragmented outlines, integrating elements into a larger context of a scene, detecting motion of multiple targets, and visual illusions (Silverstein & Keane, 2011; Uhlhaas & Silverstein, 2005). Object detection tasks that present broken figures (i.e., meaningful groupings of fragmented elements) have been one focus of research because they yield some of the largest performance gaps between schizophrenia and comparison groups (King et al., 2017; Uhlhaas & Silverstein, 2005). However, object detection tasks vary in low-level features of stimuli and linguistic demands, making it difficult to isolate the cognitive processes that contribute to performance deficits. In this study, we applied a paradigm with stimuli matched for low-level features and recorded neurophysiological responses to fragmented object representations to better characterize aberrant processes evident during object detection in severe mental illness. The study sample included individuals with schizophrenia or bipolar disorder, their first-degree biological relatives, and healthy controls, which allowed us to investigate how perceptual disturbances were associated with abnormal responses across a range of psychotic symptomatology and mental disorders during a laboratory-based object detection task.

Successful object detection relies on a highly connected and multidirectional visual perceptual network that processes sensory input and matches the input to stored representations of objects through iterative cascades of neural activity (Bar et al., 2006; de Haan & Cowey, 2011; DiCarlo et al., 2012; Yeatman et al., 2014). For the purposes of the present work, we use "object detection" to refer to detection of a known object. Thus, object detection goes beyond simply identifying isolated visual features (low-level visual processes associated with regions of the primary visual cortex such as V1 and V2) and grouping them into contours and separate image regions (intermediate processes that occur in V3, V4, and lateral occipital complex [LOC]). Object detection, as used here, requires a high-level visual recognition stage, in which the grouped contours are recognized as belonging to a familiar object. One goal of the present work was to isolate the visual cortical processes associated with assigning meaning to a visual stimulus, with minimal engagement of lexical-phonological processes required to name an object, which is an even higher-level cognitive process of substantial deficit for people with schizophrenia (Covington et al., 2005; Lau et al., 2015). In order to emphasize perceptual over lexical aspects of the stimuli, participants were not asked to name an object but instead to answer (yes/no) whether a fragmented and ambiguous stimulus represented a known object or—during electrophysiological data collection—to pay attention to the general shape (i.e., tall and skinny or short and fat) of the depicted object.

We applied electroencephalography (EEG) to isolate whether visual disruptions in people with psychotic disorders occur in early low-level processing, shortly after a visual image is captured by the eye, or in later high-level visual cortical processes tied to recognizing a known object. Early visual processing during object detection is captured by two early event-related potential (ERP) components that occur less than 200 ms after the onset of visual stimuli. P1 is a positive voltage deflection broadly linked to selective attention, arousal, and stimulus characteristics, which likely represents the initial processing of features of external sensory stimuli via the dorsal visual stream (Doniger et al., 2001). N1 is an early negative amplitude deflection that indexes discriminative processes in the ventral pathway, such as those required to distinguish the orientation of separate visual elements forming an outline (Vogel & Luck, 2000). These early components are followed by "closure negativity" (N_{CL}), a negative deflection thought to reflect grouping processes in LOC when the complete outline of an object form is perceived (Bar et al., 2006; Butler et al., 2013; Kim et al., 2009; Shpaner et al., 2013). In schizophrenia, P1 and N_{CL} are generally attenuated, while N1 remains intact (Foxe et al., 2005; Sehatpour et al., 2010; Silverstein & Keane, 2011), suggesting that object detection is disrupted at multiple levels of neural communication. P1 may be disrupted in people with high positive schizotypy as well (Bedwell et al., 2013; Koychev et al., 2010). P1 deficits could reflect anomalies in early sensory processing that cause downstream mismatches between basic sensory input and feedback from high-order processes captured in the N_{CL}, which in turn could result in perceptual disturbances (Grill-Spector et al., 2001).

Dimensional conceptualizations of psychopathology, such as the Research Domain Criteria and Hierarchical Taxonomy of Psychopathology, have been proposed to aid understanding the biological substrates of psychological phenomena (Kotov et al., 2017; Yee et al., 2015). In the current study, we leveraged two angles of the dimensional framework to better understand aspects of psychopathology associated with object detection abnormalities. First, we considered object detection across a spectrum of psychiatric disorders with shared clinical features (e.g., schizophrenia spectrum and bipolar affective disorders) and in populations with subthreshold expressions of psychosis and genetic liability for psychotic psychopathology (e.g., biological relatives). This is consistent with previous work showing that psychotic symptoms predict sensory abnormalities more closely than diagnosis across the bipolar and schizophrenia spectra (Grove et al., 2018). More generally, object detection abnormalities are associated with subclinical psychotic-like experiences and perceptual aberrations (Cicero & Kerns, 2010; DeYoung et al., 2012; Partos et al., 2016; Teufel et al., 2015; Wallace, 1990; Widiger & Crego, 2019). In community samples, participants with high positive schizotypy and those at "ultra-high risk" for psychosis are more likely to detect visually fragmented object representations as meaningful, resulting in poor performance due to high false positive rates (Partos et al., 2016; Teufel et al., 2015; Wallace, 1990). Studies of first-degree relatives are equivocal, with some yielding evidence of overinterpretation of ambiguous stimuli (Yeap et al., 2006) and others showing normative contour detection (Schallmo et al., 2013). However, past studies have not incorporated object stimuli matched on low-level visual features.

Second, we used a dimensional self-report scale of perceptual anomalies to characterize a broad range of unusual sensory experiences that range from fleeting hallucinations to immersive aesthetic experiences and may be related to visual integration abnormalities in psychosis. Many terms have been used to describe perceptual phenomena related to the psychosis spectrum. In the current study, we refer to the construct as "perceptual absorption" (Tellegen & Atkinson, 1974). Perceptual absorption is a form of apophenia, a term historically used to describe the process by which delusional beliefs are formed (Conrad, 1958). Today, apophenia is used more generally to refer to the tendency to ascribe meaning to ambiguous sensory stimuli, such as detecting animal forms in clouds.

Apophenia is associated with object detection abnormalities including detecting visually fragmented object representations as meaningful, thereby manifested in poor performance on object detection tasks due to high false positive rates (Cicero & Kerns, 2010; DeYoung et al., 2012; Partos et al., 2016; Teufel et al., 2015; Wallace, 1990; Widiger & Crego, 2019). In the current study, we used ERP components to characterize the pathological process that leads to poor perceptual organization and is expressed in heightened perceptual absorption observed in psychotic psychopathology. We expected high perceptual absorption would be related to neural abnormalities and the tendency to find meaning in ambiguous visual stimuli that are typically viewed as meaningless.

The current study involved administration of the fragmented ambiguous object task (FAOT; Olman et al., 2019), which consists of fractured representations of semantically rich images—such as plants, animals, everyday objects, and furniture—designed to be indistinguishable in low-level visual features. FAOT stimuli are classified as meaningful, ambiguous, or meaningless to differentiate high endorsement of meaningful stimuli (i.e., good perceptual organization) from abnormal or indiscriminate endorsements across stimulus types. Stimuli classifications allowed us to investigate poor perceptual organization that resulted from an inability to detect object forms (i.e., low overall FAOT score across all categories) from overendorsement of meaningless stimuli (i.e., higher false alarms). We expected that perceptual absorption would be positively correlated with FAOT performance, indicating that this aspect of psychopathology is tied to more readily seeing objects in ambiguous stimuli. This would be consistent with perceptual absorption being elevated in psychosis and our hypothesis that it leads to a lower threshold for ascribing meaning to sensory stimuli. We hypothesized that the early P1 component would be attenuated for participants with psychosis and related to more frequent detection of meaning in FAOT stimuli, indicative of disruptions in early visual processing that reflect poorly constrained object detection. Likewise, we expected complementary dimensional analyses would reveal perceptual absorption to be inversely associated with P1, indicative of a neural vulnerability for ascribing meaning to ambiguous stimuli.

Method

Participants

T1 The sample ($N = 130$; see Table 1) included individuals with a schizophrenia spectrum disorder ($n = 35$) or bipolar disorder ($n = 29$), first-degree biological relatives of persons with a schizophrenia spectrum ($n = 24$) or bipolar ($n = 17$) disorder, and healthy controls ($n = 25$). Participants were recruited from the Minneapolis Veterans Affairs Health Care System (VAHCS) and mental health centers in the Minneapolis community as part of a larger research protocol that included neurocognitive, MRI, and additional electroencephalography procedures.

Participants were native English speakers, 18 to 60 years old, with normal or corrected hearing and vision, and IQ of at least 70. Participants with a history of intellectual disability were excluded. Patients and controls were additionally excluded for substance abuse or dependence within the past 6 months; history of electroconvulsive therapy, epilepsy, diagnosed seizure disorder, stroke, or neurological condition; uncontrolled medical condition likely to substantially affect brain functioning (e.g., untreated thyroid condition); and head injury resulting in fractured skull or more than 30 min unconsciousness. Healthy controls were also excluded for history of primary psychotic disorder or hypomania, antipsychotic medication use, current or past depressive episodes, attention-deficit/hyperactivity disorder or other learning disability, and family history of bipolar or psychotic disorder.

Participants underwent diagnostic evaluation that included a structured clinical interview to assign a ~~*Diagnostic and Statistical Manual of Mental Disorders*~~ (~~4th ed.; text rev.~~) diagnosis (American Psychiatric Association, 2000; First et al., 1997). Relatives and controls additionally completed the Structured Interview for Schizotypy to assess for Cluster A personality traits and disorders (Kendler et al., 1989). Final diagnostic decisions were made through consensus of at least two trained, clinical staff (PhD or clinical graduate student level) who had not served as interviewer. All participants had the capacity to understand the study procedures and completed an informed consent process in accordance with the Declaration of Helsinki. Compensation was provided commensurate to the visit time and procedures. The University of Minnesota and Minneapolis VAHCS Institutional Review Boards both provided approval and monitoring of the study.

Measures

Clinical Scales

Clinical interviewers rated current symptomatology of all participants using a semistructured interview for the 24-item version of the Brief Psychiatric Rating Scale (Lukoff et al., 1986). Antipsychotic prescription medication dosages were converted to chlorpromazine equivalents for all patients (Andreasen et al., 2010; Leucht et al., 2016; see Table 1).

Visual Acuity

All participants completed visual acuity measures from 1 m during the EEG session. Performance was quantified by log of the minimum angle of resolution (LogMAR) units, with higher values signifying poorer acuity. Measurements were made using any corrective lenses participants wore during the visit.

Perceptual Absorption

Participants completed three personality measures that robustly assessed normative, schizotypal, and clinical ranges of unusual perceptual experiences: the Multidimensional Personality Questionnaire (MPQ) absorption subscale, Personality Inventory for *DSM–5* (PID-5), and Schizotypal Personality Questionnaire (SPQ). The Sensory Gating Inventory (SGI), a measure of perceptual phenomenology, was also completed. Two effort questions were included in the questionnaires during administration to assure that participants comprehended and attended to questions. For all questionnaires, subscales were scored when 10% or fewer of the items within the subscale were missing. A composite perceptual absorption score was then calculated using the relevant subscale within each administered self-report questionnaire: MPQ absorption (34 items; Tellegen & Atkinson, 1974), PID-5 perceptual dysregulation (12 items; Krueger et al., 2012), SPQ positive schizotypy factor (24 items; Oezgen & Grant, 2018), and SGI perceptual modulation (16 items; Hetrick et al., 2012). Standardized (Z score) values were calculated for each of the four subscales; subscales were standardized before calculating the perceptual absorption composite so that they would be evenly weighted within the composite score. The

Table 1
Sample Characteristics

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N (% male)	CON 25 (48%)	R-BP 17 (47%)	R-SZ 24 (33%)	BP 29 (62%)	SZ 35 (63%)	Statistic $\chi^2 = 6.51$
Age	47.48 (9.54)	41.59 (11.84)	47.21 (9.10)	46.28 (10.77)	45.66 (9.03)	$F(4, 129) = 1.08$
Race						
White	0	2	1	3	8	
Black	1	0	0	0	1	
Hispanic	24	14	22	26	24	
Other	0	1	1	0	2	
WRAT IQ	100.17 (6.96)	98.00 (11.83)	102.00 (6.20)	99.00 (9.19)	96.31 (12.21)	$F(4, 129) = 1.37$
Visual acuity	.10 (.13)	.03 (.08)[de]	.09 (.13)	.12 (.13)[b]	.15 (.14)[b]	$F(4, 129) = 2.72$*
FAOT (object detection rate)	.36 (.15)	.40 (.15)	.41 (.22)	.47 (.22)	.38 (.16)	$F(4, 129) = 1.49$
Perceptual absorption	−.68 (.39)	−.25 (.69)	−.36 (.58)	.55 (.92)	.36 (.91)	$F(4, 129) = 12.86$*
Chlorpromazine equivalent[f]	—	—	—	2.17 (2.01)	15.36 (25.22)	$F(4, 136) = 2.39$
BPRS (symptom ratings)						
Positive	4.04 (.20)[e]	4.65 (2.03)[e]	4.04 (.20)[e]	4.83 (1.36)[e]	7.74 (4.05)[abcd]	$F(4, 129) = 13.83$*
Negative	3.28 (.74)[e]	3.76 (1.60)	3.13 (.61)[e]	3.86 (1.46)	4.26 (2.13)[ac]	$F(4, 129) = 2.71$*
Depression/anxiety	4.92 (1.82)[de]	6.76 (2.51)[d]	6.46 (2.72)[d]	9.28 (5.42)[abc]	8.29 (3.85)[a]	$F(4, 129) = 5.79$*
Mania/activation	4.64 (1.44)[e]	5.06 (1.39)	4.42 (.65)[e]	5.21 (1.72)	5.60 (2.08)[ac]	$F(4, 129) = 2.46$*

Note. Standard deviation is listed in parentheses, except where noted. Visual acuity is reported in LogMAR units, measured while participants wore any corrective lenses used during the visit; LogMAR of 0 is equivalent to 20/20 vision with higher scores indicative of worse acuity. Fragmented ambiguous object task (FAOT) values are proportion of stimuli detected as meaningful objects during the behavioral task. Perceptual absorption scores are standardized. WRAT IQ = Wide Range Achievement Test (WRAT-III) reading subtest intelligence quotient; BPRS = Brief Psychiatric Rating Scale; CON = health controls; R-BP = relatives of people with bipolar disorder; R-SZ = relatives of people with schizophrenia; BP = bipolar disorders; SZ = schizophrenia spectrum disorders.
[a]Differed from CON. [b]Differed from R-BP. [c]Differed from R-SZ. [d]Differed from BP. [e]Differed from SZ. [f]Six participants with SZ were not taking antipsychotics; of these, one was unmedicated, while the remainder were on an antidepressant, mood stabilizer, antianxiolytic, or a combination. Twelve participants with BP were not prescribed antipsychotics; four had no psychoactive prescription, and eight took an antidepressant, a mood stabilizer, or both. Within R-SZ, one had a depressive disorder and self-reported taking 1 mg of risperidone daily. Of R-BP, one had obsessive-compulsive disorder and paranoid personality disorder and reported taking 5 mg aripiprazole daily. Healthy controls did not report any antipsychotic prescriptions.
AQ: 7 * $p < .05$, post hoc group comparisons.

four standardized subscale scores were then averaged to derive the final perceptual absorption composite score.

Neuropsychological Measures

The reading subtest of the Wide Range Achievement Test (3rd ed.; Wilkinson, 1993) was administered by trained research staff
AQ: 2 ~~as~~ an estimate of premorbid intelligence.

FAOT

Stimuli were fractured representations of objects (384 × 384 pixels) formed by regularly spaced line segments oriented to describe object features, embedded in a surround of uniformly oriented line segments (see Figure 1). All line segments were identically sized and white, contrasting with a solid gray background. The stimulus design controlled for low-level visual stimulus features: Each image was comparable in number of white and gray pixels, number of line segments, and orientation distribution. Likelihood of collinearity was also the same for all stimuli to control for midlevel feature grouping. The stimuli were of varying ambiguity whereby some images contained clearly detectable objects (i.e., meaningful objects), some objects were identified by the minority of viewers (i.e., meaningless objects), and others fell in between (i.e., ambiguous objects). FAOT was programmed in PsychoPy2 and viewed from a distance of 133 cm so that the subtense of the grid of line segments was 9.0° (Olman et al., 2019).

F1

Two versions of the task were administered: a behavioral task in which participants explicitly judged whether there was a known object in the image and an implicit version during EEG recording in which participants implicitly judged the rough dimensions ("tall and skinny" or "short and fat") of the same object stimuli. The behavioral version was administered on an Apple computer in predesignated laboratory space at the Minneapolis Veterans Affairs Health Care System. Participants viewed 100 images randomly selected from the larger pool of 217 images. Each image was preceded by a white fixation dot on a gray screen with a randomly jittered delay of 500 to 1,200 ms. Stimuli were displayed for 1,000 ms or until the participant made a response (up to 7,000 ms), whichever was longer. For each image, participants indicated whether they could see a known object in the image (yes/no) as quickly as possible using a customized button box. After responding to the 100 images, participants were shown the "yes" objects again and were asked to explicitly name each object. These naming data were not used in the current analysis. Behavioral performance was quantified as the total number of "yes" responses in proportion to the total number of responses to measure the frequency with which participants distinguished object contours prior to explicitly naming the object. Stimuli were categorized into three conditions based on detection frequency across all participants: meaningful, ambiguous, and meaningless. The overall detection rate was calculated for the full set of FAOT behavioral data after excluding participants with low response rates (<75% of images) or those with clear response bias (>95% "yes" responses or >95% "no" responses). The ends of the detection rate distribution, based on quartiles, formed the meaningful and meaningless conditions. The meaningful condition encapsulated the 53 most frequently detected images (>60% detection rate). The meaningless condition was formed by the 53 images with the lowest detection frequency (<23% detection rate). The remaining 111 images formed the ambiguous category.

The EEG version of FAOT was completed later in the visit on a PC computer in an EEG recording suite at Minneapolis Veterans

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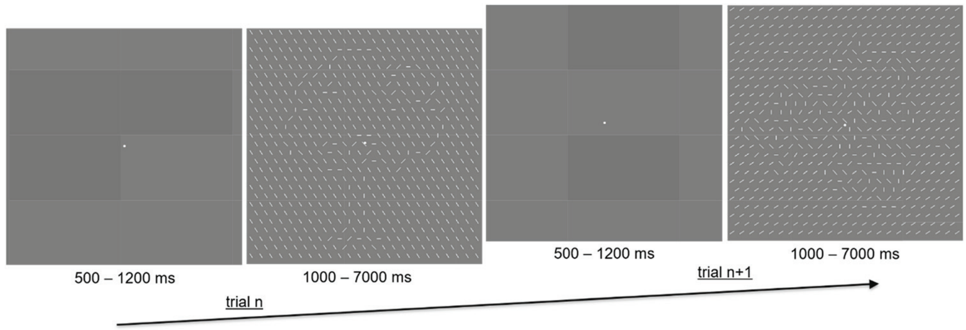
Figure 1
FAOT Paradigm



Note. Stimuli are partial representations of real-life objects set within visual noise, with some objects more easily discernible than others (see Olman et al., 2019, for a full overview of task development and stimuli characteristics). In the behavioral task, 100 randomly selected images are displayed from the complete set of 217. Participants indicated whether or not the stimulus contained a known object (yes/no). A fixation screen appeared between response trials; the fixation dot was fixed across all trials to prevent neural response to the offset. For the stimuli shown, over 84% of participants detected a known object in the first image (tree), whereas only 10% detected an object in the second image (jigsaw puzzle piece).

Affairs. Participants viewed all 217 images in random order during continuous EEG data collection. Participants indicated the image dimensions (“short and fat” or “tall and skinny”). The instructions were chosen to encourage implicit processing of objects as opposed to explicit identification to minimize semantic processing through naming of objects (Li et al., 2009). As in the behavioral version, a fixation screen was initially displayed with a randomly varying duration from 2,000 to 2,700 ms to prevent trial overlap. Participants then viewed each image for 1,000 ms followed by a fixation screen until they responded; trials aborted after 7,000 ms if there was no response. The fixation dot remained static across the task to avoid neural response to the fixation disappearing. EEG task duration was approximately 10 min.

EEG Procedures

EEG recordings were made with a BrainVision actiCHamp EEG system. The recording cap contained 128 active electrode channels conforming to the unified optimized layout based on the 10–20 international system (Chatrian et al., 1998). Impedances were less than 100 kΩ. Continuous data were collected at a 1,000-Hz sampling rate referenced to Cz. Electrodes were placed above and below the right eye and on the left and right temples to monitor eye movement. After completion of recording, data were imported to Matlab (Mathworks, Inc.) for offline processing: high-pass filtered from 0.5 Hz to 256 Hz;[1] resampled to 256 Hz employing the Matlab resample function, which uses an antialiasing filter with what is effectively a half-amplitude cutoff of 120 Hz; and rereferenced to the average signal across scalp electrodes.

Fn1 AQ: 3 [this footnote should immediately follow "Hz" prior to the semicolon.]

Filtering, artifact rejection and correction, and spherical spline interpolation for bad electrodes were carried out through a semiautomated Matlab toolbox, ICAcleanEEGv1.3, which uses independent components analysis to isolate physiological and environmental artifacts (Kang et al., 2015). Specifically, potential horizontal and vertical eye movement, muscular activity, and cardiac artifacts were identified based on an automated process in ICAcleanEEG; trained research staff then reviewed all independent components and refined classifications based on topography and time course of the continuous signal. Final classifications were determined based on consensus of research staff. Data were epoched from 500 ms prestimulus to 1,500 ms poststimulus. Mean amplitude was subtracted from the baseline period of −200 to 0 ms prestimulus. Epoched data underwent a low-pass Butterworth filter with a half-amplitude cutoff of 30 Hz; then, single-trial mean ERP components were calculated.

ERP components were quantified as mean amplitude across a cluster of adjacent electrodes. P1 included electrodes P5/P3/P4/P6 from 80 to 140 ms. N1 included occipital sites O1/Oz/O2 from 100 to 200 ms based on maximal signal. N_{CL} included electrodes PO7/PO3/PO4/PO8 from 270 to 320 ms. One additional component, a negative deflection consistent with N400, was identified through post hoc visual observation and measured using electrodes C1/Cz/C2 from 250 to 400 ms. The signal was internally consistent in each cluster of electrode sites (Cronbach's α = .85−.99), implying that each cluster captured a common signal.

Principal components analysis (PCA) was employed to reveal latent ERP components that may not be detectable via visual inspection of grand average ERP waveforms, incorporate a broader scalp distribution of electrodes in component quantification, and consider the full range of FAOT stimulus ambiguity (meaningful, ambiguous, and meaningful). The time-domain PCA was conducted on subject average ERP components (as opposed to single-trial waveforms) via the ERP PCA Toolkit (Version 2.69; Dien, 2010). An oblique (promax) rotation was used, which loosens orthogonality constraints for rotated factors (i.e., factors may remain correlated after rotation). A four-factor solution was selected based on visual identification of the scree plot and inspection of the factor waveforms/topographies. The

[1] High-pass filter cutoff was selected to facilitate use of independent components analysis for artifact identification and removal for the high-density electrode montage and because hypotheses were directed at early, brief-duration ERP components. A lower high-pass filter cutoff would have been preferable for optimal characterization of the exploratory analysis of late slow components of the ERP (see Duncan-Johnson & Donchin, 1979).

temporal factors derived from this four-factor solution shared spatiotemporal features with the traditionally identified ERP components (see Figure 2). Factors were derived in order of the variance explained (e.g., the first factor isolated the most variance), with 61% of the total variance explained by the PCA solution. The topography of the first factor was consistent with a late positive component maximal at Pz at 645 ms, an ERP we had not considered in planned analysis. The second factor was maximal at PO7/PO8 at 348 ms, approximating the N_{CL} component. The third factor was maximal at occipital site Oz at 180 ms, consistent with the timing and topography of N1. The fourth and final PCA factor showed the earliest deflection, maximal at 121 ms at Oz, similar to the P1 ERP. We then extracted the mean amplitude of each temporal factor from 0–1,000 ms for each participant for each condition. It should be noted that in this context, the time-window choice is arbitrary because the relationship between factor scores for each participant at each condition does not change as a function of time. Thus, group and condition effects are irrespective of time-window choice. The advantage of extracting and analyzing mean amplitude values rather than the factor scores themselves is that the mean amplitude values are microvolt scaled and thus are arguably more interpretable than factor scores.

Statistical Analysis

Statistical analysis was carried out in SPSS Statistics v26. Before performing the multilevel models, chi-square tests of independence were carried out on all ERP, FAOT, and personality measures to ensure the assumption of independence was not violated by family membership (e.g., two participants being siblings). Our past analyses show minimal to no contribution from family clusters (Pokorny et al., 2019; Silberschmidt & Sponheim, 2008). Likewise, none of the variables in the current sample violated independence; thus, family membership was not included as a random effect. Last, variance inflation factor and tolerance levels were inspected to avoid multicollinearity. All analyses showed acceptable levels of variance inflation factor (<5) and tolerance ($>.2$).

A series of general linear models (GLMs) was constructed to test the two main hypotheses. The first GLM tested whether stimulus condition, visual acuity, and group predicted responses on the FAOT behavioral task. The dependent variable was FAOT performance, as quantified by "yes" responses indicating the participant saw a known object among the fragmented stimulus elements. Stimulus condition (meaningful, ambiguous, meaningless) and participant group were entered as independent variables; gender and visual acuity were included as predictors to ensure effects were not driven by differences in these characteristics. The second set of GLMs tested whether FAOT performance, stimulus condition, visual acuity, and group predicted neurophysiological responses during the FAOT; eight GLMs were carried out, one for each ERP component and PCA factor. The dependent variable was mean amplitude of the ERP component or the PCA factor. Stimulus condition (meaningful vs. meaningless) was included as a within-subject factor in the ERP models. To consider stimulus meaningfulness more broadly in PCA analyses, stimulus condition was considered at three levels (meaningful, ambiguous, meaningless). As with the initial model, group, gender, and visual acuity were included as predictors. For all models, sphericity could not be assumed, so Greenhouse-Geisser corrections were used for within-subjects tests.

Results

FAOT Behavioral Performance

Detection rates of meaningful objects on the FAOT behavioral task were comparable across participant groups, $F(4, 129) = 1.49$, $p = .21$ (see Table 1). Visual acuity was the strongest predictor of FAOT performance; better visual acuity was associated with higher rates of object detection, $F(1, 123) = 11.23$, $p < .01$, $r = -.24$. Note that group differences in visual acuity were driven by better visual acuity (lower LogMAR value) in relatives of individuals with bipolar disorders, $F(4, 129) = 2.72$, $p < .05$ (see Table 1); visual acuity was not different in schizophrenia, bipolar, relatives of schizophrenia, and comparison groups. Men and women did not differ in FAOT detection rates, $F(1, 123) = 2.57$, $p = .11$. There were no significant interactions between condition and between-subjects factors, indicating that detection rate did not differ across conditions as a function of group, gender, or visual acuity. Antipsychotic medication, quantified as chlorpromazine equivalence, was correlated with poorer visual acuity ($r = .36$). Thus, we carried out a follow-up analysis that restricted the sample to patients with antipsychotic prescriptions and added chlorpromazine equivalent as a variable to the statistical model. Visual acuity remained the sole significant predictor of FAOT object detection. Chlorpromazine equivalents did not correlate with FAOT performance, EEG, PCA, or perceptual absorption variables, so follow-up analyses of antipsychotic medication effects were not conducted for other analyses.

FAOT EEG Findings

For analyses of EEG data, we first considered predictors of ERP mean amplitude differences (see Figure 3). Then, in order to have a broader spatial and temporal representation of neural responses within the EEG signal, we tested how the four PCA factors were predicted by the same within- and between-subjects factors (see Figure 2). The findings for the PCA factors largely paralleled those of ERP analyses.

P1

P1 did not differ based on diagnostic group, $F(4, 123) = 1.42$, $p = .23$, visual acuity, $F(1, 123) = .02$, $p = .89$, gender, $F(1, 123) = .25$, $p = .62$, or stimulus condition, $F(1, 123) = .49$, $p = .48$. Likewise, the fourth PCA factor, which most closely approximated P1, was not significantly affected by diagnostic group, $F(4, 123) = 2.08$, $p = .09$, gender, $F(1, 123) = .07$, $p = .80$, stimulus condition, $F(2, 123) = .19$, $p = .83$, or visual acuity, $F(1, 123) = 3.64$, $p = .06$, $r = .23$. There were no significant interactions between factors for P1 or the fourth PCA factor.

N1

The N1 component was sensitive to stimulus condition but did not differ across participant group. N1 was larger (i.e., more negative) for meaningless than meaningful stimuli, $F(1, 123) = 17.64$, $p < .0005$, 95% CI [−.46, −.17]. N1 amplitude was unaffected by visual acuity, $F(1, 123) = 2.01$, $p = .16$, group, $F(4, 123) = 1.63$, $p = .17$, and gender, $F(1, 123) = .27$, $p = .61$. Like N1, we found the third PCA factor was amplified in response to meaningless stimuli, $F(2, 123) = 6.76$, $p < .05$, [−.04, −.01]. The third factor did not vary as a function of group,

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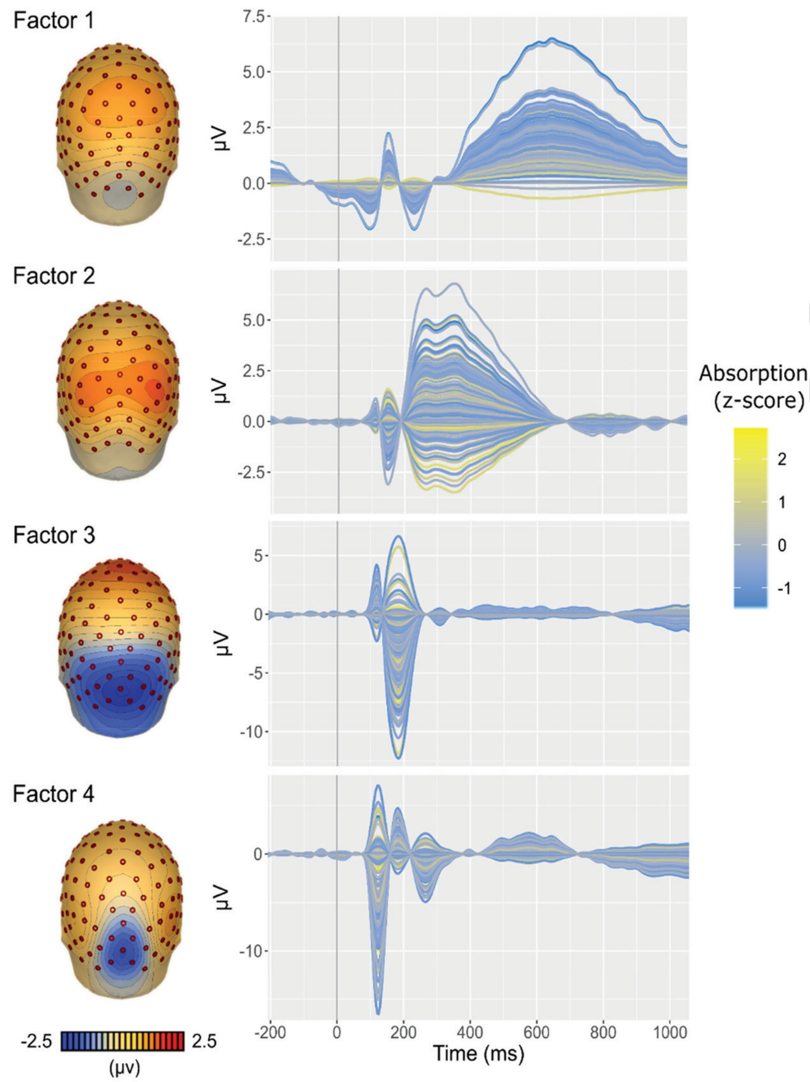
Figure 2

The Four-Factor PCA Solution



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Note. Four-factor PCA solution used to identify aspects of the neural response that were separable across time and scalp recording location. Butterfly plots depict a single temporal factor waveform for each subject (*n* = 130) averaged across stimulus conditions, with ~~a brighter yellow color~~ representing higher perceptual absorption scores for individuals (labeled "Absorption" in the figure). There was a general correspondence to conventional ERP components; however, the PCA-derived temporal factors helped isolate elements of the neural response while representing broader aspects of each component beyond a few select electrode sites. Topographies represent the electrode sites at which each factor loaded most heavily. PCA waveforms are derived by multiplying the loading for each time point of a factor by the factor score for a given subject. See the online article for the color version of this figure.

$F(4, 123) = 1.49$, $p = .21$, visual acuity, $F(1, 123) = .57$, $p = .45$, or gender, $F(1, 123) = .60$, $p = .44$. There were no significant interactions for the N1 component or PCA factor.

N_{CL}

N_{CL}, the negative deflection that has been associated with visual "closure" of fragmented objects, did not significantly differ with FAOT condition, $F(1, 123) = 3.03$, $p = .08$, visual acuity, $F(1, 123) = .02$, $p = .89$, or group, $F(4, 123) = .57$, $p = .69$. Men trended toward more pronounced N_{CL} deflections than women, $F(1, 123) = 3.85$,$p = .052$. The second PCA factor, which was similar to N_{CL} in time course, varied by condition with larger deflection to meaningful than meaningless stimuli, $F(2, 123) = 9.62$, $p < .0005$, 95% CI [−.09, −.03], consistent with the component representing perceptual closure for an object. The factor was at the threshold of significance for being larger in men, $F(1, 123) = 2.43$, $p = .051$. Neither visual acuity, F(1,

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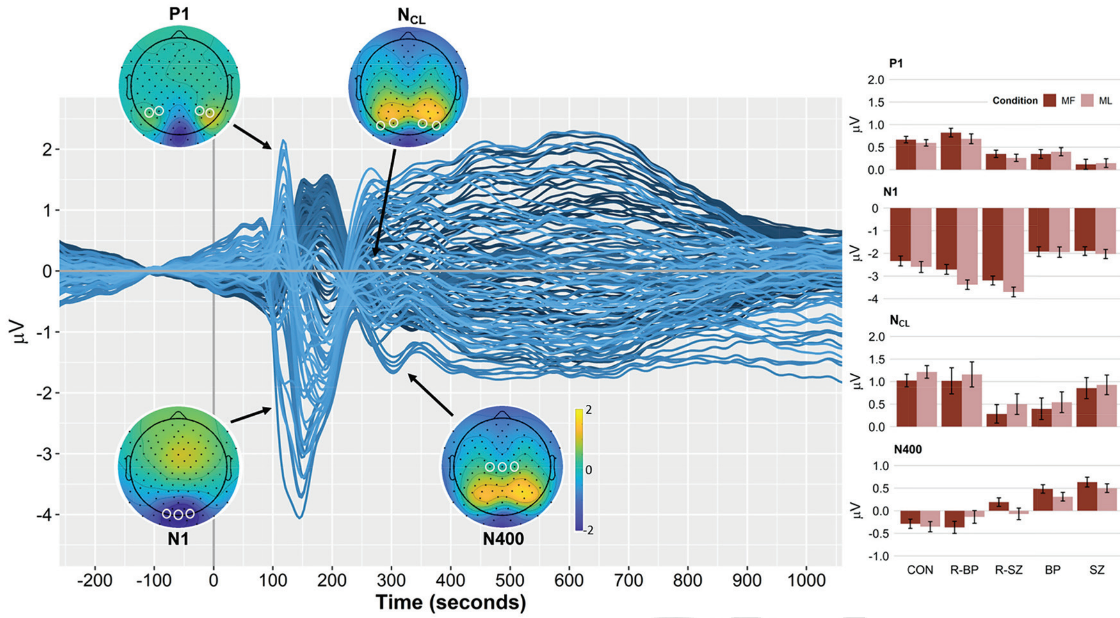
Figure 3

ERP Response to FAOT Stimuli



Note. ERPs in response to fragmented and ambiguous object stimuli. Waveform lines represent individual electrode channels; shading is used to distinguish channels. Inserts are scalp topographies of four ERP components—P1, N1, N_{CL}, N400—with arrows indicating the feature of the ERP that is represented. At right, plots illustrate the mean amplitude of the ERP components for stimuli judged to contain meaningful (MF) and meaningless (ML) objects. There was a larger negative N1 deflection for meaningless than meaningful stimuli, $F(1, 123) = 17.64$, $p < .001$, 95% CI [−.46, −.17]. None of the ERP components significantly differed in amplitude across groups. Error bars represent standard error; electrode sites of interest are highlighted by circles on scalp topographies. CON = healthy controls; R-BP = relatives of people with bipolar disorder; R-SZ = relatives of people with schizophrenia; BP = bipolar disorder; SZ = schizophrenia. See the online article for the color version of this figure.

123) = 2.26, $p = .14$, nor participant group, $F(4, 123) = .95$, $p = .44$, significantly predicted the second factor. Condition did not significantly interact with other factors for N_{CL} or the PCA factor.

N400

A group effect of N400 was at the threshold of significance, $F(4, 123) = 2.36$, $p = .06$. There were no effects of condition, $F(1, 123) = 1.35$, $p = .25$, visual acuity, $F(1, 123) = .01$, $p = .97$, or gender, $F(1, 123) = 1.10$, $p = .30$; there were no significant interactions.

Late Positive Component

The first PCA factor that was maximal later in the time course of the ERP showed a marginally significant effect of FAOT stimulus condition, with ambiguous stimuli eliciting the largest deflection, $F(2, 123) = 2.89$, $p = .06$. The first factor did not vary based on visual acuity level, $F(1, 123) = 2.06$, $p = .15$, group, $F(1, 123) = .56$, $p = .69$, or gender, $F(1, 123) = 1.18$, $p = .28$, or interactions between predictors.

Perceptual Absorption Findings

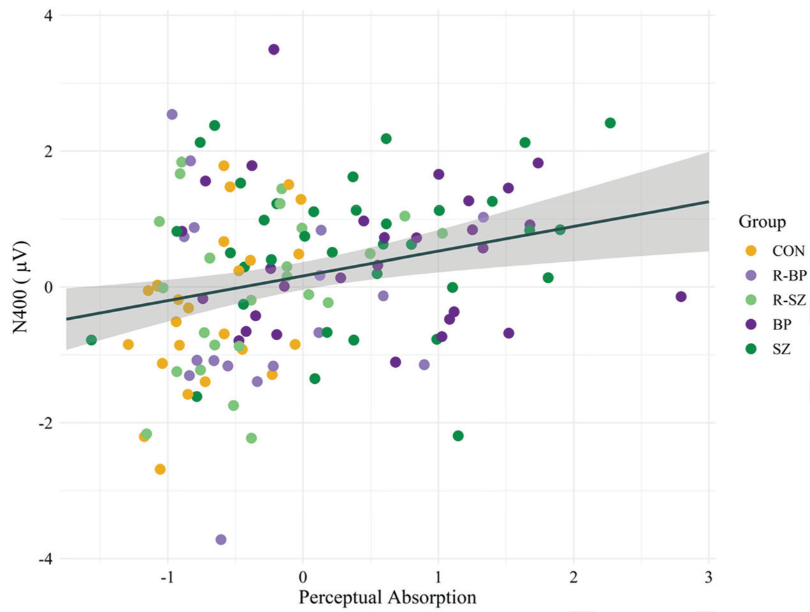
Perceptual absorption, a composite personality scale, was distributed across the participant groups in the expected pattern: Schizophrenia and bipolar groups exhibited significantly higher perceptual absorption than relatives and controls in post hoc tests, and relatives were intermediate to patients and controls by visual inspection, $F(4, 129) = 12.86$, $p < .0005$. Whereas diagnostic group failed to account for notable variance in FAOT behavioral performance, higher perceptual absorption was at the threshold of significance for positively predicting higher rates of FAOT object detection, $F(1, 126) = 3.69$, $p = .057$.

Perceptual absorption also predicted attenuation of EEG responses, even after accounting for contributions of condition, visual acuity, and gender. The N400 was smaller for participants with higher perceptual absorption, $F(1, 126) = 6.67$, $p = .01$, $r = .26$ (see Figure 4). F4 The first PCA factor was also reduced at higher levels of perceptual absorption, $F(1, 126) = 4.43$, $p = .04$, $r = −.23$ (see Figure 2, ~~yellow-tinted~~ waveforms). AQ: 4 No other ERP component or PCA factor was significantly associated with perceptual absorption (p values from .15 to .67).

Discussion

We investigated whether aberrant perception of fragmented objects arose from low-level or higher-order visual functions in individuals with severe psychopathology, with increased genetic liability for psychosis, or with no history of psychosis. Stimuli appraised as containing meaningful objects generated smaller early (N1) and larger midlatency responses over visual cortical regions that were unrelated to psychotic psychopathology. Later ERP responses (N400 and a late positive component) reflective of higher-level semantic appraisals of visual stimuli were related to psychotic psychopathology measured using a dimensional scale of perceptual absorption. Results provide

Figure 4
Association Between Perceptual Absorption and EEG Response



Note. The N400 component (250–400 ms at Cz/C1/C2), often associated with semantic appraisal, was attenuated (i.e., amplitude was more positive) for those who reported higher levels of perceptual absorption (values reported as standardized scores). Shading depicts standard error. CON = healthy controls; R-BP = relatives of people with bipolar disorder; R-SZ = relatives of people with schizophrenia; BP = bipolar disorder; SZ = schizophrenia. See the online article for the color version of this figure.

evidence that perceptual aberrations are a specific aspect of psychotic psychopathology that is related to high-level visual functions elicited by ambiguous stimuli and are less dependent on deviant low-level visual processes. The findings are also consistent with a transdiagnostic model of psychosis, wherein a specific symptom domain is related to deviations in perceptual processing.

Though differences across the five groups failed to reach statistical significance, the neurophysiological response to stimuli with recognizable (meaningful) objects differed from that of largely unrecognized stimuli. The N1 and analogous PCA factor were amplified for meaningless stimuli, whereas the PCA analogue of N_{CL} was amplified for meaningful stimuli. The N1 is traditionally viewed to reflect low- and midlevel visual processes. In this instance, object stimuli had comparable low-level features; therefore, augmentation of the N1 was likely influenced by midlevel processes elicited by form perception. The augmentation of the PCA analogue of N_{CL} for meaningful object stimuli aligns with perceptual closure also being influenced by high-level processes related to object perception. Given sensitivity of N1 and N_{CL} to the presence of recognizable objects and LOC activations sensitive to objects revealed through the use of the same stimulus set (Pokorny et al., 2020), early ventral stream processing embodied in N1 and N_{CL} responses may reflect LOC-mediated integration of sensory inputs with semantic predictions related to high-level functions elicited during recognition of ambiguous objects.

The current study revealed that low-level object detection embodied in the P1 response was largely unrelated to psychotic psychopathology. Instead, later aspects of processing object stimuli (N400 and late positive component reflected in the first PCA factor) appear most related to aberrant perception. Neither N400 nor a late positive component have been incorporated into previous studies of object detection, though the disruptions have been broadly documented in schizophrenia (Bharath et al., 2000; Wang et al., 2011). Both components are related to semantic processing of stimuli, which may be evoked by variation in the meaningfulness of FAOT stimuli. N400 indexes the degree of semantic processing of both linguistic and nonlinguistic stimuli and modulates based on the familiarity of a stimulus (e.g., well-known as opposed to novel objects; Abdel Rahman & Sommer, 2008; Kutas & Federmeier, 2011). People with higher perceptual absorption are prone to ascribe meaning to random percepts, making it less likely that a stimulus would be unfamiliar or out of context. Thus, we would expect high perceptual absorption to be associated with attenuated N400 responses. Likewise, the late positive component would be expected to be attenuated with increased familiarity of object stimuli as a result of higher perceptual absorption (Dima et al., 2011; Regel et al., 2014). Perceptual absorption can include extremes in sensory experiences such as positive symptoms. Thus, the current results may reflect a relationship between altered expectancies for sensory input that contribute to perceptual organization deficits and the perceptual disturbances evident in psychotic symptomatology. Researchers have previously posited that hallucinations and delusions may derive from deviant expectations about sensory characteristics of stimuli (Silverstein & Thompson, 2015).

The finding that a dimensional measure of perceptual absorption is associated with aspects of object processing (N400 and the late positive component) complements recent work. In our studies of undergraduate samples, apophenia predicted more false positives across a wide range of cognitive tasks in healthy and clinical samples and was inversely correlated with frontal lobe white matter integrity (Blain et al., 2019; Grazioplene et al., 2016), supporting the idea that perceptual anomalies result from a high propensity to see meaning in coincidental sensory experiences. In the normative range of perceptual absorption, this could result in functional (e.g., innovative) percepts, while the maladaptive pole of the dimension may depart from reality in the form of aberrant percepts, perceptual organization deficits, and psychotic symptomatology.

In contrast to past research, all participants detected a comparable number of fragmented objects. Individual differences in perceptual aberrations may be more sensitive than diagnostic groupings as suggested by a trend of higher perceptual absorption scores predicting more frequent object detection. Other studies have found individuals with schizophrenia have difficulty integrating discrete visual elements to perceive contours and closed simple objects (Pokorny et al., 2019; Silverstein et al., 2015). An important difference is that FAOT consists of a semantically rich set of stimuli for which the participant determines whether there is meaning in the ambiguous stimulus, while perceptual integration tasks in nearly all studies require simple discrimination between two objects or discrete locations of contour. The content and unconstrained number of possible percepts derived from FAOT stimuli allows greater influence of semantic processes. Results of the current study support the idea that although people with schizophrenia poorly integrate visual elements into simple features, real-world experiences of distorted perception as measured by perceptual absorption are most strongly related to high-level semantic processes. Perceptual integration deficits in schizophrenia may result in greater ambiguity forming a percept, thereby creating vulnerability for semantic distortions during object detection. The results point to multiple approaches that can be further explored in the perceptual integration literature: false alarms or *d* prime, ambiguous stimuli, matched low-level stimuli, implicit engagement of semantics, and assessing individual differences.

Diagnostic delineations also failed to yield between-group differences in ERP component amplitude (e.g., N1, N_{CL}) and in the equivalent PCA factors, although there were trends for differences across the five groups in the amplitudes of the PCA analogue of the early P1 component and the N400 reflective of semantic processing. Thus, when low-level characteristics of visual stimuli are controlled, and explicit identification of objects is minimized because of instructions to orient to form, diagnoses of psychotic disorders do not appear to be strongly associated with abnormal processing of object stimuli.

Another important consideration is that visual acuity was the strongest predictor of object detection, with better visual acuity being related to more frequent object detection. Previous work has shown that subtle variations in visual acuity, even at levels that are not deemed impaired, result in reduced contour detection (Keane et al., 2015). Visual perceptual abnormalities arising from precortical ocular phenomena, such as retinal aberrations and poorly corrected vision, may contribute to sensory disturbances as well (Silverstein & Rosen, 2015; Viertiö et al., 2007).

Conclusion

This study adds to visual perception research in psychosis by drawing connections between clinical phenomenology, visual functions supporting object detection, and semantic processing. Early and midlatency brain responses primarily associated with visual processes were modulated when a meaningful object was discerned in ambiguous stimuli. Later neural responses that are typically reflective of semantic processing were associated with individual differences in self-reported perceptual aberrations (i.e., perceptual absorption), suggesting that individuals high in perceptual absorption may more freely ascribe meaning to ambiguous stimuli and exhibit neural responses indicative of aberrant high-level perceptual functions. The findings suggest that dimensional measures of personality are sensitive to variation in biological systems relevant to psychotic symptomatology and object perception across a spectrum of psychosis presentations and severities.

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