An electrophysiological investigation of attentional blink in schizophrenia: Separating perceptual and attentional processes

Kristopher I. Mathis, Jonathan K. Wynn, Carol Jahshan, Gerhard Hellemann, Alexandra Darque, Michael F. Green

VA Desert Pacific Mental Illness Research, Education, and Clinical Center (MIRECC), VA Greater Los Angeles Healthcare System, West Los Angeles VA Healthcare Center, 11301 Wilshire Blvd., Bldg 210, Room 130, Los Angeles, CA 90073, USA

Jane & Terry Semel Institute for Neuroscience and Human Behavior, University of California, Los Angeles, 760 Westwood Plaza, Los Angeles, CA 90095, USA

Laboratory of Experimental Neuropsychology, Geneva University Hospital, Geneva, Switzerland

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ABSTRACT

When two visual targets are presented in a rapid serial visual presentation (RSVP) paradigm, the ability to identify the second target is reduced when it is presented 200–500 ms after the initial target. This phenomenon is referred to as the “attentional blink (AB).” Previous behavioral studies have reported aberrant AB in schizophrenia. The underlying cause, however, of the AB deficit in schizophrenia remains ambiguous. Individuals with schizophrenia consistently demonstrate impairments in early visual processing stages and later attentionally-mediated stages, yet the stage of processing that is contributing to patient-control differences on AB is unknown. The current study attempted to resolve this ambiguity by applying electrophysiological methodology to an RSVP paradigm with 70 clinically stable outpatients with schizophrenia and 63 healthy controls. The task was simplified to reduce task demands, and a suppression ratio was employed to control for possible differences between groups in the ability to identify a single stimulus within a visual stream. Early perceptual processing was assessed using the steady-state visual evoked potential (ssVEP), and attentional processing was assessed using the P300 event-related potential. Relative to the healthy controls, patients showed the expected behavioral AB deficits. These deficits coincided with reduced P300 amplitude: both performance and P300 reductions extended beyond the traditional AB window. Mean ssVEP amplitude did not differ between the groups, and the differences in P300 remained after controlling for ssVEP. These results suggest that the observed AB deficits were due to attentional, not perceptual, processing deficits.

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1. Introduction

Previous work has demonstrated that several aspects of early visual processing are impaired in schizophrenia, but relatively little attention has been given to later stages in the visual processing stream that involve the transition from perceptual to attentional processes. To assess this stage of processing, specialized paradigms are used in which simple visual stimuli are shown in a rapid serial visual presentation (i.e., RSVP paradigms). When two target stimuli (T1 and T2) are presented among a stream of distractor stimuli in a RSVP paradigm, the result is an “attentional blink” (AB). Specifically, the ability to identify T2 is degraded when it is presented within 200–500 ms after T1. The precise explanation for the AB is debated, but most theories posit that the processing of T1 demands resources that temporarily impair the processing of T2 (Chun and Potter, 1995; Dux and Marois, 2009; Martens and Wyble, 2010). Hence, the RSVP paradigm and the AB effect provide an excellent means to evaluate the later stages of visual processing and the early stages of attention in schizophrenia.

To date, four studies of AB in schizophrenia have been published (Cheung et al., 2002; Li et al., 2002; Mathis et al., 2011; Wynn et al., 2006). Generally, these studies suggest that the AB effect is exaggerated in schizophrenia, but questions remain regarding the factors underlying this exaggerated response (i.e., the blink is longer and/or deeper). One question is where in the perception-to-attention processing stream the abnormalities lie. Another question is whether group differences in the AB could be due to response to overall task demands.

Regarding the relevant processing stage, the AB involves elements of both early perceptual and attentional processing (Martens and Wyble, 2010). Hence, the behavioral deficit alone is not informative regarding which process accounts for the deficits seen in schizophrenia. Electrophysiological measures, including event-related potentials (ERPs) can assess specific stages of perceptual and attentional processing. In the current study, we employ the steady-state visual evoked potential (ssVEP) and the P300 component of the event-related potential (ERP)
to assess earlier and later stages, respectively. The ssVEP reflects visual processing associated with activation of the primary visual cortex (Vialatte et al., 2010) and is thought to reflect basic, early perceptual processing of stimuli. The P300 reflects later, more cognitively complex, processing, such as attentional allocation, working memory encoding, and stimulus consolidation, associated with activation of frontal and temporal-parietal areas (Polich, 2007). When applied to the RSVP paradigm, the ssVEP provides a reflection of early visual response to the entire train of stimuli, whereas the P300 is time locked to the targets and reflects later visual processing. Both the ssVEP and the P300 have been investigated using RSVP paradigms in nonclinical samples, including several designed to elicit an AB (Brisson et al., 2009; Dell’Acqua et al., 2003, 2007; McArthur et al., 1999; Vialatte et al., 2010).

Both ssVEP and P300 have been examined in patients with schizophrenia. Overall, the data from ssVEP have been mixed, but there is relatively consistent evidence for disruption of the ssVEP in patients within frequency bands associated with perceptual processes (e.g., alpha band activity: 8–13 Hz and beta band activity: 13–30 Hz) (Brenner et al., 2009; Kim et al., 2005, 2006; Krishnan et al., 2005). Reduction of the P300 response is a well-established finding in the schizophrenia literature (Jeon and Polich, 2000, 2003). Generally, this reduction is thought to reflect impaired attentional allocation and basic memory function. To date, ssVEP and P300 have not been examined within the AB paradigm to assess the visual processing in schizophrenia.

Regarding the question of task complexity, it is possible that the task demands are more taxing on the patients than the controls. Hence, another goal of the current study was to limit the task complexity and minimize task demands by using a dual target (T1 and T2) task with a simple 2-way forced choice for both targets. Our previous AB studies used a more complex RSVP task that had a relatively large number of possible responses for the targets.

In the current study we attempted to evaluate the previously-reported exaggeration in AB through the use of EEG in a large sample of controls and patients with schizophrenia. In this study, we used a simplified version of the RSVP paradigm and assessed the contributions to AB of early perceptual processes using the ssVEP and later, attentional processes using the P300.

2. Method

2.1. Participants

The sample consisted of 70 (14 female) patients with a DSM-IV diagnosis of schizophrenia and 63 (18 female) healthy comparison subjects. Patients were recruited from the outpatient treatment clinics of the VA Greater Los Angeles Healthcare System (VAGLAHS) and from board-and-care residences in the community through staff presentations and referral. Diagnoses were confirmed using the patient version of the Structured Clinical Interview for DSM-IV Axis I Disorders (SCID-P) (First et al., 1997) and clinical symptoms were evaluated using the expanded 24-item UCLA version of the Brief Psychiatric Rating Scale (BPRS) (Ventura et al., 1993) and the Scale for the Assessment of Negative Symptoms (SANS) (Andreasen, 1984). All the clinical assessments were conducted by interviewers trained to reliability by the Treatment Unit of the VISN 22 Mental Illness Research, Education, and Clinical Center (MIRECC). Sixty patients were receiving second-generation antipsychotic medications, 3 were receiving first-generation antipsychotic medications, 4 were receiving both types of antipsychotics, and 3 were not taking an antipsychotic medication at the time of assessment.

Healthy comparison subjects were recruited through newspaper and internet advertisements and were screened using the SCID-P and SCID-II (First et al., 1996). They were excluded from participation if they had a personal or family history of psychotic illness, or if they met criteria for any lifetime bipolar disorder, recurrent depression, substance dependence, or avoidant, schizoid, schizotypal, and paranoid personality disorders. Visual acuity was assessed for all participants using a Snellen eye-chart. Exclusion criteria for both groups included corrected visual acuity worse than 20/40, ages <18 or >60, IQ below 70 based on chart review, active substance use disorder in the preceding 6 months, an identifiable neurological disorder or a history of loss of consciousness lasting longer than 1 h, or insufficient fluency in English. Enrolled participants provided written informed consent after all procedures were fully explained in accordance with procedures approved by the Institutional Review Boards at UCLA and the VAGLAHS.

2.2. Procedures

Two rapid serial visual presentation (RSVP) tasks consisting of a stream of targets and distractors were presented to each participant. The distractors in both tasks were the numbers 1–9. Both tasks were developed and presented using E-Prime software, v1.1. (Psychological Software Tools, Pittsburgh, PA). All stimuli were black presented on a gray background, and were displayed on a cathode ray tube monitor set to a refresh rate of 160 Hz. The monitor was positioned 1 m in front of the participants. The monitor was leveled and centered within the visual field of each individual participant. All stimuli were subtended 2° of visual angle. Each stimulus in the RSVP was presented for 62.5 ms and was followed by a 25 ms inter-stimulus interval during which the computer monitor displayed a blank screen.

The first task, the single-target task, employed only one target that was either an “X” or a “Y.” In the single-target task, a sequence of 2–5 distractors preceded the presentation of the target and a sequence of 14–17 distractors succeeded the target. The second task, the dual-target task, included an initial target (T1) that was either a vowel (A, E, O, or U) or a consonant (C, J, R, or T), and a second target (T2) that was either an “X” or a “Y.” T1 and T2 were separated by three different lags consisting of either 0 (lag 1), 1 (lag 2), or 6 (lag 7) distractors. In the dual-target task, a sequence of 1–6 distractors preceded the presentation of T1 and 12–16 distractors succeeded the presentation of T2, dependent on the lag. Forty trials at each lag were presented for a total of 120 (Fig. 1).

For both single- and dual-target tasks, each trial began with a fixation cross displayed in the center of the screen for 500 ms followed by a blank screen displayed for 400 ms. Twenty total stimuli (including distractors and targets) were then presented for each RSVP sequence (i.e., trial). After each RSVP sequence a 1000 ms blank screen was displayed. A screen containing all of the potential target choices was then displayed and prompted the participant to identify the correct target.

![Fig. 1](https://example.com/fig1.png)
the target(s). The experimenter entered the participants’ verbal responses using the keyboard after each trial, after which the experimenter initiated the next trial.

The single-target task provides an assessment of group differences in ability to identify a target in a rapid stream of stimuli and enables the calculation of a suppression ratio (SR) that controls for differences in single target detection when examining dual-target task performance (Estes and Skinner, 1941). The SR reflects the ratio of a participant’s performance on the dual-target task to the participant’s combined performance on both tasks. SR scores range from 0 to 1, with 0.5 indicating no change in dual task performance relative to the single-target task. Hence, an AB effect in the dual task condition would be reflected in a low SR score (less than 0.5). The SR score indicates how much of the group difference between patients and controls goes beyond difficulty in identifying targets in a rapidly-presented stream.

2.3. EEG recording

EEG was continuously recorded during the attentional blink task using a 64-channel Neuroscan SynAmps2 amplifier and a Neuroscan 64-channel QuickCap (Compumedics USA, Charlotte, NC). The amplifier was AC-coupled and the data were acquired at 500 Hz with a bandpass filter of 1 to 100 Hz. Horizontal electrooculogram (EOG) was recorded from a bipolar electrode array consisting of sensors placed adjacent to the lateral canthi of the left and right eyes and vertical EOG was recorded from a bipolar electrode array consisting of sensors placed on the superior and inferior orbital margins of the left eye, in-line with the pupil. EEG was recorded from the scalp electrodes relative to an active reference electrode located halfway between electrodes Cz and CPz. An electrode affixed to the forehead, inferior to FP1/FP2, served to ground the array.

2.4. EEG data analysis

All data were processed offline using Neuroscan Scan 4.3 and BrainVision Analyzer 2 software (Brain Products, Gilching, Germany). Ocular artifact in the EEG was identified and corrected using a standard regression algorithm derived from manual identification of eyeblink exemplars for each subject (Semlitsch et al., 1986). Following removal of ocular artifact, the EEG data were re-referenced to the mathematical average of the activity recorded at the left and right mastoid sites (averaged mastoids). The re-referenced EEG was segmented into 2 s epochs beginning 500 ms before the onset of each target until 1546 ms after onset in the RSVP. This interval was selected to provide an appropriate (i.e., base-2 compatible) number of data points for the ssVEP analyses. A linear detrending algorithm was applied to each epoch to correct for electrical drift over the course of the recording session. The data were then corrected for differences in baseline voltage algorithmically using the 500 ms prestimulus interval. Visual inspection of trials was then performed to eliminate any remaining abnormal EEG responses. Epochs that contained electrical activity exceeding ±75 μV were excluded from further analyses (avg. rejection rate for both groups: 15%). The remaining epochs were low-pass filtered (zero phase shift) at 30 Hz with a 24 dB/octave roll off and averaged to reflect the EEG activity across all trials within a particular condition.

To assess the ssVEP, we conducted a Fast Fourier Transform (FFT) using a Hamming window with a 10% taper on the averaged data for each condition. This procedure yielded mean spectral amplitude within the 10–12 Hz frequency band, which corresponds to the rate of presentation for stimuli in the RSVP task. Initially, we looked at spectral amplitude separately for 3 electrodes on the left (P03, P05, P07) and 3 electrodes on the right (P04, P06, P08), corresponding to areas of scalp associated with visual processing. We did not find any laterality differences, so the analyses in this paper include values for the 6 electrodes averaged together.

For the P300 component, averaged data for each condition were low-pass filtered at 5 Hz, with a 24 dB/octave roll off to remove ssVEP activity from the EEG. The P300 was then identified as a positive-going waveform that peaked between 300 and 600 ms after stimulus onset. The peak P300 activity within this window was identified for each condition. Inter-electrode differences were examined for peak P300 activity across three midline sites (Cz, Pz, and Oz) identified in the literature as the sites of maximal relevant activity. As shown in Fig. 2, the distribution of activity across the scalp for the P300 is consistent previous findings, and the peak P300 values at each electrode site are reported in Table 2. No significant effect for electrode site was found, thus we averaged the peak P300 activity from these sites for all subsequent analyses. Peak P300 activity from these midline sites was identified for each target and compared across groups and lags.

2.5. Statistical approach

To assess group differences in demographic characteristics, independent samples t-tests were used for continuous variables, and X² tests were used for discrete variables. Any variables that showed significant group differences were explored further to account for possible effects on the results. For the single target task, univariate ANCOVAs were used to assess group differences on target identification, mean ssVEP amplitude, and peak P300 amplitude. We used age as a covariate for all variables, and we conducted analyses both with and without ssVEP as a covariate for P300. For the dual target task, a 2 (group) × 3 (lag)
repeated measures ANCOVA was employed to assess task performance. For the EEG analyses, only two lags were considered (i.e., lags 2 and 7). At lag 1, ERP activity generated by target 1 cannot be separated from ERP activity generated by target 2, thus lag 1 is omitted from the analyses. Accordingly, mean ssVEP spectral amplitude and peak P300 amplitude elicited by the targets during the dual target task were examined using (2 (group) × 2 (lag) repeated measures ANCOVAs. Significant interactions were investigated using univariate ANCOVAs and Bonferroni-corrected contrasts. For repeated measures with more than one degree of freedom, we used Greenhouse–Geisser correction factors (ε) to correct for violations of sphericity. We report the uncorrected degrees of freedom, the corrected p-value, and ε. All statistical analyses used a two-tailed significance level of 0.05.

3. Results

3.1. Demographic and clinical characteristics

Schizophrenia patients were significantly older relative to healthy controls, t(131) = 4.59, p < 0.001 and had significantly less parental education, t(122) = 1.83, p < 0.05. The gender distributions of the samples did not differ, X^2 = 1.33, p > 0.05. As shown in Table 1, schizophrenia patients exhibited mild levels of symptoms at the time of testing. Symptomatology did not significantly correlate with performance on either RSVP task. Given the significant difference in age between the groups, we included age as a covariate in all subsequent analyses (i.e., ANCOVAs). Parental education did not correlate with any of the variables of interest and was, therefore, not included as a covariate.

3.2. Task performance

The patients’ performance (84% mean accuracy) on the single-target task was significantly impaired compared to the controls’ performance (92% mean accuracy), F(1,133) = 23.38, p < 0.001. On the dual-target task, performance (SR) is shown in Fig. 3. The repeated measures ANCOVA revealed significant main effects for lag; F(2,260) = 3.30, p < 0.05, ε = 0.90; and group; F(1,130) = 8.51, p < 0.05. No significant interaction effects were found. The main effect for lag reflects the expected lag 1 sparing and an attentional blink effect at the later lags for both groups. The main effect for group reflects significantly impaired performance on the dual-target task for the patients after accounting for the basic performance deficits observed on the single-target task. Planned pairwise comparisons showed that performance at lag 7 was significantly improved relative to lag 2 in the control sample, t(62) = 2.67, p < 0.05, but not in the patient sample, t(69) = .69, ns.

3.3. ssVEP amplitude

The results of the ANCOVAs for mean ssVEP amplitude during the single-target task revealed no main effect for group. As shown in Table 2, mean ssVEP amplitudes were 0.58 μV and 0.50 μV for the controls and patients, respectively. The results for the dual-target task revealed no significant main effects for group or lag and no interaction between those variables after controlling for age, all ps > 0.05. For the dual-target task, mean ssVEP amplitudes for lags 2 and 7 are displayed in Table 2.

3.4. P300 amplitude

For the single-target task, the ANCOVA revealed a significant main effect for group on peak amplitude of the P300 (F_{1,130} = 12.43, p < 0.01). Specifically, the patients showed diminished P300 amplitude (1.30 μV) associated with presentation of the target stimulus, relative to the controls (1.83 μV). Controlling for ssVEP amplitude in addition to age yielded the same results (F_{1,129} = 10.66, p < 0.01).

Table 1

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Schizophrenia patients (N = 70)</th>
<th>Healthy participants (N = 63)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Age (years)</td>
<td>45.73</td>
<td>9.94</td>
</tr>
<tr>
<td>Parental education</td>
<td>12.35</td>
<td>2.99</td>
</tr>
<tr>
<td>Duration of Illness</td>
<td>22.66</td>
<td>10.85</td>
</tr>
<tr>
<td>BPRS total score</td>
<td>44.62</td>
<td>10.21</td>
</tr>
<tr>
<td>SANS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affective flattening</td>
<td>1.58</td>
<td>1.33</td>
</tr>
<tr>
<td>Alogia</td>
<td>0.98</td>
<td>1.45</td>
</tr>
<tr>
<td>Avolition</td>
<td>2.22</td>
<td>1.41</td>
</tr>
<tr>
<td>Anhedonia</td>
<td>2.66</td>
<td>1.76</td>
</tr>
<tr>
<td>Gender</td>
<td>14/56</td>
<td>18/45</td>
</tr>
</tbody>
</table>

* Brief Psychiatric Rating Scale.

** SANS, Schedule for the Assessment of Negative Symptoms.

Table 2

<table>
<thead>
<tr>
<th>Amplitude (μV)</th>
<th>Schizophrenia patients (N = 70)</th>
<th>Healthy participants (N = 63)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SE</td>
</tr>
<tr>
<td>ssVEP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single target</td>
<td>0.50</td>
<td>0.04</td>
</tr>
<tr>
<td>Dual target − lag 2</td>
<td>0.46</td>
<td>0.03</td>
</tr>
<tr>
<td>Dual target − lag 7</td>
<td>0.44</td>
<td>0.04</td>
</tr>
<tr>
<td>P300 − midline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single target</td>
<td>1.30</td>
<td>0.10</td>
</tr>
<tr>
<td>Dual target − lag 2</td>
<td>0.76</td>
<td>0.07</td>
</tr>
<tr>
<td>Dual target − lag 7</td>
<td>1.05</td>
<td>0.09</td>
</tr>
<tr>
<td>P300 − CZ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single target</td>
<td>1.57</td>
<td>0.13</td>
</tr>
<tr>
<td>Dual target − lag 2</td>
<td>0.84</td>
<td>0.08</td>
</tr>
<tr>
<td>Dual target − lag 7</td>
<td>1.32</td>
<td>0.12</td>
</tr>
<tr>
<td>P300 − PZ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single target</td>
<td>1.24</td>
<td>0.11</td>
</tr>
<tr>
<td>Dual target − lag 2</td>
<td>0.71</td>
<td>0.07</td>
</tr>
<tr>
<td>Dual target − lag 7</td>
<td>1.11</td>
<td>0.12</td>
</tr>
<tr>
<td>P300 − OZ</td>
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<td></td>
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<tr>
<td>Single target</td>
<td>1.09</td>
<td>0.11</td>
</tr>
<tr>
<td>Dual target − lag 2</td>
<td>0.72</td>
<td>0.15</td>
</tr>
<tr>
<td>Dual target − lag 7</td>
<td>1.00</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Fig. 3. Dual-target task performance. Identification accuracy represented by the suppression ratio at each lag for each group. Both group and lag had significant main effects on performance. Bars represent ± one standard error.
Peak P300 amplitude was essentially unchanged by the inclusion of ssVEP amplitude in the model (1.32 μV for patients; 1.81 μV for controls).

For the dual-target task, the repeated measures ANCOVA found significant main effects for lag ($F_{1,130} = 5.93$, $p < 0.05$) and group ($F_{1,130} = 10.54$, $p < 0.05$) and a significant interaction for lag × group ($F_{1,130} = 17.25$, $p < 0.001$). The main effect for lag reflects the absence of the P300 at lag 2 in both groups. The main effect for group reflects diminished P300 amplitude for the patients relative to the controls. The interaction effect was characterized by the lack of a significant between-group difference at lag 2 ($F_{1,130} = 0.26$, $p > 0.05$; see Fig. 4) and a significantly larger P300 in the control sample at lag 7 ($F_{1,130} = 11.49$, $p < 0.001$; see Fig. 5). At lag 2, the P300 is mainly missing for both groups as they experience a strong AB (see Fig. 4). Including mean ssVEP amplitude as an additional covariate in the analyses yielded essentially identical results. These results suggest that later stage processing of the second target was markedly disrupted during the AB in both groups, but that the patients demonstrated a longer disruption due to the AB, and this difference remained after controlling for earlier perceptual processing.

To assess whether P300 response to target 2 at lag 7 was equivalent to P300 response in the absence of the attentional blink, we compared the peak P300 elicited by target 2 to the peak P300 elicited by target 1 at lag 7. In the control sample, peak P300 to target 2 did not differ from peak P300 to target 1 during lag 7 ($F_{1,67} = 0.00$, $p > 0.05$). In the patient sample, peak P300 to target 2 was significantly smaller than the peak P300 to target 1 during lag 7 ($F_{1,60} = 4.99$, $p < 0.05$). This finding further indicates that the AB is disrupting visual processing beyond the traditional AB timeframe.

ANCOVA is only one approach to account for the potential confounding effects of age on the dependent variables, and we conducted a secondary analysis after applying a median split on the patient sample based on age. Younger patients did not differ in age from the control participants. The findings on the EEG measures between younger patients only and controls were the same as those for the entire patient sample. Also, younger patients did not significantly differ from older patients for any of the main variables.

4. Discussion

The present study sought to clarify the nature of AB impairment in schizophrenia. Previous studies of the AB in schizophrenia, including ours, have focused on behavioral abnormalities and the interpretation of these abnormalities has been ambiguous because AB impairment could result from either early perceptual or slightly later attentional problems.

The current study revealed several findings that tend to implicate attentional, rather than perceptual, abnormalities as the main contributor to the AB differences. First, there were no differences between groups on the measure of perceptual processes (ssVEP). Second, P300 amplitude tracked well with AB performance, and AB differences between groups. There were no group differences for T2 at lag 2, when the AB is most pronounced. The controls, but not the patients, showed a robust P300 at lag 7. The group difference for T2 at lag 7 was greater than: 1) the group difference for T2 for the lag 2 condition, and 2) the group difference for T1 for the lag 7 condition. The impaired performance on AB does not appear to be attributable to early perceptual processing stages, as assessed with ssVEP and used as a covariate. Instead, these data suggest problems with attention, as assessed with the P300, are related to the exaggerated AB in schizophrenia.

While supporting the role of attentional processes, results from the current study do not support plausible alternative explanations for AB impairment in schizophrenia. First, the exaggerated AB in patients with schizophrenia could be due to the response to demands of increased task complexity. However, these impairments remained after reducing task demands by making the responses simple 2-way forced choices. Second, the AB deficit could be due to a more general problem in identifying a single target in a rapid visual stream. However, we used the suppression ratio approach, in which we control for single target task performance. Finally, we considered whether the patient–control differences in AB could be a downstream effect of a problem in basic perceptual processing. However, the lack of either a group difference for ssVEP or an influence of ssVEP on P300 amplitude suggests that the impaired performance and the reduced P300 amplitude in the patients at lag 7 were not downstream effects of early perceptual deficits.

One limitation of the current study is that, although we made the task simpler, there is no way to fully equate the task demands for single and dual targets. The dual task still involves the processing of two visual stimuli and the necessity of encoding both stimuli. The collection of the P300 data using an AC coupled bioamplifier also represents a possible limitation of the current study. Specifically, the 1 Hz high pass filter applied at the time of data acquisition may have removed
some of the low frequency activity that contributes to the P300 response, thus reducing the overall amplitudes of the observed responses. Another limitation is that the ssVEP is only one example of early bottom up ERPs. Other evoked potentials associated with early sensory processing stages (e.g., P100, N100, etc.) could not be accurately measured in the RSVP paradigm due to the stream of visual stimuli that were presented at 11 Hz. Steady-state VEP is a reasonable way to measure lower-level perceptual processes, though under some conditions it can be affected by directed attention, and in that sense, is not purely bottom-up (Vialatte et al., 2010). Nonetheless, there is a general consensus that it represents a type of processing that is early and distinguishable from higher-order cognitive functioning and that generally functions in a bottom-up manner (Kok, 1997).

These results are consistent with an attentional explanation for the AB impairment in schizophrenia. Because P300 reflects attentionally-mediated processing, the failure of P300 to recover in patients with schizophrenia by lag 7 indicates that attentional processing of T2 is disrupted beyond the typical AB interval. Overall, the current study used EEG methods to clarify the nature of the AB deficit in schizophrenia, revealing that the most likely explanation of group differences lies at the later, attentional, stage of processing.

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