Bimodal response sensitivity and bias in a test of sustained attention contrasting patients with schizophrenia and bipolar disorder to normal comparison group

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Abstract

This study examined response discrimination (d') and bias (likelihood ratio) differentials in a computer-generated test of auditory and visual attention functioning. Patients with bipolar disorder (n = 42) and schizophrenia (n = 47) were contrasted to a normal comparison group (n = 89) in two conditions: (a) simple modal responsivity (auditory and visual stimuli) and (b) ipsimodal (auditory/auditory and visual/visual) and crossmodal (auditory/visual and visual/auditory) responding. The results of this study indicated that in the simple modal condition both subject groups showed differential modal preferences but in opposite directions. The schizophrenic group showed a significant visual over auditory preference, committing more auditory commission and omission errors than visual errors. The bipolar group displayed a distinct auditory over visual response preference, committing significantly higher number of visual omission errors. Response bias analysis indicates that both diagnostic groups adopted a more liberal response bias, whereas the comparison group assumed a more conservative approach. For all groups response sensitivity improved as response bias became more neutral.

The modal switching results indicated that all three groups tended to commit more commission errors (false alarms) in the auditory crossmodal switching condition (visual/auditory) by comparison with the other switching conditions. Between group comparisons for this condition showed that the schizophrenic group committed significantly more commission errors than the other groups. No significant medication effects were detected.

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1. Literature review

Mettler (1955) observed that patients with schizophrenia had difficulties switching attention between sensory modalities. He attributed this difficulty to a hypothesized deficiency in the corpus striatum of schizophrenic brains. This deficiency is not only manifest in the “loss of contact” with reality most notably in the presence of hallucinations but also in the loss of the ability to efficiently communicate perceptual information. Several studies pursued this observation and examined the relationship of serial bimodal stimulus presentation and reaction time (RT) differentials on modal attention shifting (Benton, Sutton, Kennedy, & Brokaw, 1962; Kristofferson, 1967; Sutton, Hakerem, Zubin, & Portnoy, 1961; Sutton & Zubin, 1964). Sutton et al. (1961) found that patients with schizophrenia showed a marked RT latency to auditory crossmodal responding, that is, a visual stimulus followed by an auditory stimulus, when compared to normal controls. However, these same subjects showed no such latency in the ipsimodal condition, for example, an auditory stimulus followed by an auditory stimulus. This finding has been robust and replicated in the literature (Baerwald, Tryon, & Sandford, 2001; Mussgay & Hertwig, 1990; Spring, 1980; Sutton & Zubin, 1964; Verlager & Cohen, 1978; Waldbaum, Sutton, & Kerr, 1975; Wilkins & Venables, 1992).

One potential explanation for this within group modal differential has emerged in the evoked response potential (ERP) literature. Duncan-Johnson, Roth, and Kopell (1984) found that patients with schizophrenia produced lower auditory neural amplitude by comparison with their visual ERPs. This decreased amplitude may explain why the auditory RTs of schizophrenic patients are substantially delayed when switching from visual stimuli to auditory stimuli, that is, the auditory neural signal is weaker, or harder to detect, by comparison to the visual neural signal (Duncan, Morhisa, Fawcett, & Kirsch, 1987; Duncan, Perlstein, & Morhissa 1987; Duncan-Johnson & Donchin, 1979).

Most studies of sustained attention use the computer-generated Continuous Performance Test (CPT; Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956) or one of its many variants (Asarnow, Steffy, MacCrimmon, & Cleghorn, 1991; Cohler, Grunebaum, Weiss, Gamer, & Gallant, 1977; Cornblatt & Erlenmeyer-Kimling, 1985; Golberg, Gold, Greenberg et al., 1993; Halperin, Newcorn, Greenblatt, & Young, 1991; Laurent et al., 1999; Neuchterlein, 1983; Rutschmann, Cornblatt, & Erlenmeyer-Kimling, 1977). A common finding of this research is that patients with schizophrenia manifest impaired sustained attention as seen in a decrement in performance over time as well as impaired processing speed as seen in delayed RTs. Yet, similar patterns of attention dysfunction have been reported in other diagnostic groups as well, for example, affective disorder and bipolar disorder (Addington & Addington, 1997; Gates, 2000; Green & Walker, 1986; Mojtabai, Bromet, Harvey, Carlson, Craig, & Fennig, 2000; Rund, Orbeck, & Landro, 1992). While the CPT and its variants are able to distinguish pathological from normal populations, there are mixed and often contradictory findings as to the ability of these same tests to differentiate between pathological populations (cf. Van Zomeren & Brouwer, 1994).

Many of the aforementioned studies used RT latency as a measure of attention. In fact, RT measures have been shown to be very reliable indicators of general alertness (Van Zomeren & Brouwer, 1994). However, several studies (Asarnow, Steffy, & MacCrimmon, 1978; Mussgay & Hertwig, 1990; Walker, 1981; Wohlberg & Kornetsky, 1973) have consistently shown that
individuals diagnosed with schizophrenia commit a higher number of omission errors (failure to respond to a target) and commission errors (failure to inhibit responding to a foil) compared to normal controls. While these two types of errors provided significant information on test performances, some researchers (Nuechterlein, Edell, Noris, & Dawson, 1986; Nuechterlein & Parasuraman, 1983; Rutschmann et al., 1977) have recommended that signal detection theory may provide more sensitive indices: $d'$ (a measure of response discriminability or sensitivity) and $L_x$ or likelihood ratio which is a measure of response bias (also called beta; Malle, 1995) of subject responding (Nevin, 1969; Tanner & Swets, 1954). These two indices measure underlying processes of responding that are not apparent in raw omission errors, raw commission errors, or in reaction time.

Response sensitivity refers to a responder’s capacity to discriminate between a target (signal) and a foil (noise). The $d'$ index corresponds to the distance between the means of the frequency distributions generated by responses to the targets and foils. Greater overlap, represented by lower values of $d'$, indicate lower sensitivity. In other words, in such cases, the individual has difficulty discriminating between signal and noise (Kadlec, 1999).

A complimentary measure, $L_x$ corresponds to a responder’s “attitude,” often called bias, during the test (for computation, cf. Malle, 1995). Attitude, here, indicates the response bias appropriated by the test taker. If a test taker adopts a response style that seeks to minimize errors (avoid foils) there is a greater likelihood that errors of omission (missing targets) will also be made. This approach is called the conservative response bias and would be observed as under-responding. Conversely, if the test taker adopts a response style that seeks to maximize correct responses there is a greater likelihood that errors of commission (responding to foils) will also be made. This approach is called the liberal response bias and would be observed as over-responding. The value $L_x$ is the quantification of the bias. The distance of the value from absolute zero signifies increasing strength of bias. Values of $L_x < 0$ indicate that the individual took a more conservative approach, requiring more information before deciding if a stimulus was a target or foil. Values of $L_x > 0$ suggest that the individual took a more liberal approach, or greater risk taking, requiring less information before responding to a target or foil. The value of $L_x = 0$ suggests that targets and foils are treated equally. This condition is called a neutral bias, in other words, the individual demonstrates no bias.

Mussgay and Hertwig (1990) studied signal detection sensitivities between schizophrenic, alcoholics, and normal individuals using auditory, visual, and bimodal stimulus presentation. Their study found that, by comparison with alcoholic and normal participants, the group with schizophrenia showed decreased sensitivity across all stimulus conditions with the lowest $d'$ values in the bimodal stimulus condition. Response criterion beta, a measure similar to the likelihood ratio, yielded inconsistent results.

Ishigaki and Tanno (1999) studied patients with schizophrenia with and without the presence of auditory hallucinations using a visual CPT, and calculated both $d'$ and response criterion beta. This study found that those patients with auditory hallucinations showed similar response sensitivity as those patients without auditory hallucinations, yet the former group manifested a liberal response bias.

The present study evaluated response discrimination and bias in patients with schizophrenia and patients with bipolar disorder in contrast with a normal comparison group on a comput-
erized test of sustained auditory and visual attention. Based on Mussgay and Hertwig (1990) it was hypothesized that schizophrenic patients would show smaller perceptual sensitivities values across all sensory conditions compared to the comparison group. Additionally, it was hypothesized that patients with schizophrenia would show lower sensitivities in auditory conditions by comparison to visual conditions (Baerwald et al., 2001; Beatty, 1982; Duncan, 1988). Last, it was hypothesized that schizophrenic patients would show the poorest sensitivity \((d')\) in the auditory crossmodal switching condition (Mussgay & Hertwig, 1990).

While there is little research to suggest the direction of response discrimination in the bipolar group, it was hypothesized, based on reaction time results (Baerwald et al., 2001), that bipolar disorder patients’ sensitivity \((d')\) would be lower than the comparison group but not as poor as the schizophrenic group. Additionally, it was hypothesized that these patients would show lower sensitivity in the visual condition by comparison to the auditory condition. Finally, it was hypothesized that the bipolar disorder patients would show the poorest sensitivity in the visual crossmodal switching condition (Baerwald et al., 2001).

Given the inconclusive findings of Mussgay and Hertwig (1990) it was decided to not hypothesize on the direction of response bias in the two diagnostic groups. Nonetheless, it must be assumed that since there was no explicit payoff scheme (e.g., reward for correct responding) nor feedback given during testing that participants would appropriate a neutral bias, corresponding to \(L_x = 0\). Significant deviation from this neutral stance would be suggestive of an internal response bias that is not based on external reinforcement or punishment since neither was provided.

2. Method

2.1. Participants

There were 131 potential participants for this study: 95 of these (patients with schizophrenia: \(n = 51\); patients with bipolar disorder: \(n = 44\)) met inclusionary criteria: no history of head injury, no history of schizoaffective disorder, scored “within normal limits” on the Mini-Mental Status Exam (cutoff score: \(\geq 28\)), and received a concordant diagnosis from the intake and attending psychiatrists (explained below). Statistical analyses on a broad range of demographic variables showed no significant differences between those who met or failed inclusionary criteria. Subjects with invalid profiles on the Intermediate Visual and Auditory Continuous Performance Test (IVA; Sandford & Turner, 1994) were also excluded. An invalid test is one that is constituted by random responding. Six profiles (four SS and two BDS) were judged to be invalid and dropped from further analyses. The data for 89 participants was retained for analyses (patients with schizophrenia: \(n = 47\); patients with bipolar disorder: \(n = 42\)).

Each individual was an inpatient at a major metropolitan hospital at the time of testing. The majority of the participants, 75%, \((n = 65)\), were male. The age range was 18 years to 73 years, with a mean age of 37.25 years (S.D. = 12.02 years). Education ranged from sixth grade to postgraduate studies with a mean of 12.02 years (S.D. = 3.22 years). The majority of individuals were Caucasian \((n = 50)\), 25% \((n = 22)\) were African American, 13% \((n = 11)\) were Hispanic, and 6% \((n = 4)\) were Asian.
With the exception of gender (males n = 65; females n = 24; χ = 7.37, P < .006), there were no differences between groups across age, education, race, marital status, prior admissions, and age of onset.

Approximately 67% (n = 60) of the participants were voluntarily admitted for inpatient treatment. For five patients, the current hospitalization was the first; but the largest group of patients (n = 35) had been hospitalized on more than five occasions. There was no statistical significance between groups on hospital status.

Individuals were assigned to either the schizophrenic or bipolar group based on admission diagnosis made by the admitting psychiatrist that was later confirmed by the diagnosis of the attending inpatient psychiatrist. Diagnosis was made on the basis of patient history, observation, clinical interview and assessment of symptoms. If a subject received another or additional Axis I diagnosis from the attending physician the subject was excluded from participation. There were six admitting psychiatrists with a mean of 5.3 years (S.D. = 1.65) of psychiatric experience. The attending psychiatrist had more than 21 years of inpatient psychiatric experience. While the administration of a standardized diagnostic measure would have been preferable, the limitations of collecting data in a clinical setting did not make this possible. Given the insistence on 100% intake and attending diagnostic concordance, it is unlikely that major diagnostic mistakes were made with subjects solicited for study participation. Of the patients with schizophrenia, 87% (n = 41) received a DSM-IV diagnosis of Paranoid Schizophrenia, four subjects were diagnosed with Undifferentiated Schizophrenia, and two subjects were diagnosed with Disorganized Schizophrenia. Of the patients with bipolar disorder, 34% (n = 15) were diagnosed in the manic cycle, 24% (n = 10) in the depressed cycle, and 40% (n = 17) were diagnosed with mixed features.

In addition to the above cohorts, a restricted age range pool of individuals (18–91 years old) that was used to norm the IVA (Sandford & Turner, 1995) was applied as a comparison group. This group is not a true control group in that the exclusionary criteria were different than those applied to the research group. This population is a super-normal sample in that cognitive deficits or psychological disorders that would be found in a “true” random normative selection were excluded. The exclusionary criteria were: history of head injury, neurological compromise, learning disability, or Attention Deficit/Hyperactivity Disorder. There were 286 participants who comprised the adult normative data pool. A decision was made to match the comparison group with research participants on age and sex. This decision was based on the findings of significant main effects for age and sex for attention variables on the IVA (Sandford & Turner, 1994), and that there is a significant sex difference between research groups. While matching reduced statistical power it was used to increase explanatory validity. The age and sex demographics of the comparison group (n = 89) mirror those of the research subjects.

2.2. Instrument

The IVA is a counterbalanced intermixed computer-generated test of continuous auditory and visual attention. The actual test is 13 min in duration (with registration, instruction, and practice the length of the test is approximately 20 min in duration). The test is simple and boring. The test taker is to push a mouse button (placed on the dominant side) when a “1” is seen or heard, and not to push the mouse button when a “2” is seen or heard. The test was
designed to “pull for” errors of impulsivity and attention by creating response disinhibition and inhibition sets.

The hardware requirements for IVA are detailed elsewhere (Sandford & Turner, 1995). These requirements were followed in the collection of the current data.

IVA is structured in four modules. The first module, called the “warm up” module, is a sensory/motor subtest of visual and auditory target (“1”) stimuli. The first 10 stimuli are visual targets followed by 10 auditory targets. This module establishes baseline RT functioning. The second module is a practice module to establish comprehension of task requirements. The third module is the actual test. The fourth module, called the “cool down” module, repeats the first module.

The main section, the third module, of IVA consists of five sets of 100 trials each. Each set is equally divided into two blocks. Each trial is 1.5 s in duration. Visual stimuli are approximately 1.5 in. in height and presented for 167 ms; auditory stimuli are presented for 500 ms.

In the first test block, the ratio of target stimuli (“1”) to foil stimuli (“2”) is 6.25 to 1 (42 targets and 8 foils). This block pulls for errors of impulsivity by presenting strings of targets interrupted by an auditory or visual foil. The second block reverses the target to foil ratio. This block pulls for inattention by presentation of strings of foils interrupted by a target. The second block is a mirror of the first block in that a target for the first block corresponds to a foil in the second block, or a foil in the first block corresponds to a target in the second block. The presentation of the stimuli is pseudo random, but fixed for all test takers, preventing an individual from guessing which type of stimuli will appear next.

All stimuli are presented binocularly and binaurally. If a patient reported the need to wear glasses for reading they were instructed to wear glasses during testing. The volume control was adjusted to a comfortable level.

3. Results

Before the primary statistical analyses were conducted, two one-way ANOVAs were run on the three bipolar disorder diagnostic categories—depressed, mixed, and manic—to evaluate potential heterogeneity of performance on mean auditory and visual $d'$. No statistically significant differences were found between these groups for either condition, $F(2, 39) = 3.02$, ns, and, $F(2, 39) = 1.92$, ns, for, respectively, visual and auditory conditions. All further analyses combined these groups.

3.1. $d'$ auditory and visual response sensitivity

Calculation of conditional probabilities for hits and false alarms was followed using the procedure established by Green and Swets (1966). In cases when no errors were made, a constant correction = .1 was added as recommended by Davies, Jones, and Taylor (1984).

Table 1 presents the mean values for each of the groups for hits and false alarm probabilities across visual and auditory conditions. The $d'$ data were analyzed using a 3 between (schizophrenic, bipolar disorder, and comparison group) by 2 within (visual and auditory modalities) ANOVA. There was a main effect for group, $F(1, 175) = 57.04$, $P < .001$,
Table 1
Means, standard deviations, and ranges for probabilities of hit and false alarm rates and $d'$ across subject groups

<table>
<thead>
<tr>
<th>Mode</th>
<th>Schizophrenic group</th>
<th>Bipolar disorder group</th>
<th>Comparison group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>S.D.</td>
<td>Range</td>
</tr>
<tr>
<td>Hit rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0.86</td>
<td>0.15</td>
<td>0.18–0.99</td>
</tr>
<tr>
<td>V</td>
<td>0.89</td>
<td>0.13</td>
<td>0.48–0.99</td>
</tr>
<tr>
<td>False alarm rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0.06</td>
<td>0.01</td>
<td>0.01–0.38</td>
</tr>
<tr>
<td>V</td>
<td>0.06</td>
<td>0.06</td>
<td>0.01–0.25</td>
</tr>
<tr>
<td>$d'$</td>
<td>A</td>
<td>3.03</td>
<td>0.93</td>
</tr>
<tr>
<td>V</td>
<td>3.24</td>
<td>0.96</td>
<td>1.22–4.79</td>
</tr>
</tbody>
</table>

A: auditory; V: visual.

\( \eta^2 = .40, \) as well as group by modality interaction, \( F(2, 175) = 12.26, P < .001, \eta^2 = .12. \) No significant main effect was detected for modality. Bonferroni adjusted post hoc analysis for main effect showed that each group is significantly different (schizophrenic < bipolar disorder < comparison group) from each other.

Between groups post-tests (t test for pooled variances) showed that by comparison to the comparison group, the patients with schizophrenia showed the poorest response discrimination (\( P < .001 \)) and the patients with bipolar disorder showed the second poorest response discrimination (\( P < .001 \)).

Within-subject comparison found that visual response discrimination was significantly better than auditory response discrimination, \( t(46) = 3.14, P < .003, \) for the schizophrenic group. For the bipolar disorder group, the opposite pattern was detected, \( t(41) = -3.28, P < .002. \) No statistical difference was found between auditory and visual response discrimination for the comparison group.

### 3.2. Auditory and visual response bias

Since the IVA presents auditory and visual stimuli in a pseudorandom pattern, the likelihood ratios were computed for all auditory and all visual trials. We are not presuming that individuals shifted their response strategies for each trial. Rather, given that there are modal differences in response sensitivity (previous analysis), we are asking if there is something about the nature of the stimulus itself, either in perception or cognitive judgment, which potentially creates modal response bias sets.

The means and standard deviations for the visual $L_0$ condition were, Schizophrenic: $M = 0.04, \text{S.D.} = 0.08$; Bipolar Disorder: $M = 0.04, \text{S.D.} = 0.09$; Normal: $M = -0.01, \text{S.D.} = 0.03$. The means and standard deviation for the auditory $L_0$ condition were: Schizophrenic: $M = 0.05, \text{S.D.} = 0.07$; Bipolar Disorder: $M = 0.03, \text{S.D.} = 0.07$; Normal: $M = -0.01, \text{S.D.} = 0.02$. To examine $L_0$ differentials between groups the data were analyzed using a 3 between (schizophrenic, bipolar disorder, and comparison group) by 2 within (visual and auditory $L_0$). The between factor analysis yielded a significant main effect, \( F(2, 175) = 27.08, P < .001, \)
There was no within-subject modality effect, $F(1, 175) = 0.41, ns$, nor a group by modality interaction, $F(2, 175) = 1.63, ns$. Between group post-tests (Bonferroni post hoc analysis) showed that $L_x$ was significantly different for the comparison group relative to both the schizophrenic group ($P < .001$) and bipolar disorder group ($P < .001$). No statistical difference was detected between patients with schizophrenia and patients with bipolar disorder.

3.3. Correlation between response discrimination and response bias

Pearson product moment correlations were computed between $d'$ and $L_x$ for both auditory and visual conditions. The scatterplots for these correlations are presented in Figure 1a and b. The correlations between discrimination and bias indices in the auditory condition were $r(47) = -.53$, $r(41) = -.47$, and $r(87) = .41$ for, respectively, schizophrenic, bipolar disorder, and comparison groups. The correlations between discrimination and bias indices in the visual conditions were, $r(47) = -.51$, $r(41) = -.54$, and $r(87) = .74$ for, respectively, schizophrenic, bipolar disorder, and comparison group. All correlations were significant at the .001 level.

3.4. $d'$ ipsimodal and crossmodal response sensitivity

The IVA data was additionally coded into ipsimodal and crossmodal responses. For purposes of analyzing ipsimodal (i.e., auditory to auditory, visual to visual) and crossmodal (i.e., visual to auditory, auditory to visual) responding, only data in the frequent hit blocks, that is, the first 50 trials of each of the five sets, were coded. The purpose of this coding was to include only those trials when attention is measured, as opposed to the frequent foil blocks when inattention is measured. Moreover, only contiguous and independent groupings of stimuli were coded, that is, each set had to include at least two target stimuli (e.g., Target, Target, Foil). The total numbers of trials across the five test blocks are: auditory to visual, $n = 55$; visual to auditory, $n = 50$; visual to visual, $n = 30$; auditory to auditory, $n = 25$. Descriptive data for this analysis are found in Table 2.

The $d'$ data were analyzed using a 3 between (schizophrenic, bipolar disorder, and comparison group) by 4 within (auditory ipsimodal, visual ipsimodal, auditory crossmodal, and visual crossmodal switching) ANOVA. A significant between group main effect was detected, $F(2, 175) = 58.36, P < .001$, $\eta^2 = .40$. Bonferroni post hoc analyses revealed that by comparison to the comparison group, both the schizophrenic group ($P < .001$) and bipolar disorder group ($P < .001$) showed lower discrimination. Additionally, the schizophrenic group response discrimination is significantly lower than that of bipolar disorder group ($P < .001$).

The within group analyses showed a significant main effect for modal switching, $F(3, 525) = 368.72, P < .001$, $\eta^2 = .68$, as well as a significant group by modal switching interaction, $F(6, 525) = 4.90, P < .001$, $\eta^2 = .05$. Table 3 reports post hoc analyses on the ipsimodal and crossmodal comparisons among groups.

\footnote{One outlier bipolar patient was removed from analysis in both visual and auditory analyses.}
Fig. 1. Scatterplots of likelihood ratio by response sensitivity for (a) auditory condition and (b) visual condition.
Table 2
Means, standard deviations, and ranges of hit rate and false alarm probabilities and $d'$ by group

<table>
<thead>
<tr>
<th>Mode</th>
<th>Schizophrenic group</th>
<th>Bipolar disorder group</th>
<th>Comparison group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>S.D.</td>
<td>Range</td>
</tr>
<tr>
<td><strong>Hit rate</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AA</td>
<td>0.88</td>
<td>0.14</td>
<td>0.20–1.00</td>
</tr>
<tr>
<td>VA</td>
<td>0.86</td>
<td>0.16</td>
<td>0.15–1.00</td>
</tr>
<tr>
<td>VV</td>
<td>0.90</td>
<td>0.12</td>
<td>0.55–1.00</td>
</tr>
<tr>
<td>AV</td>
<td>0.87</td>
<td>0.13</td>
<td>0.45–1.00</td>
</tr>
<tr>
<td><strong>False alarm rate</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AA</td>
<td>0.04</td>
<td>0.05</td>
<td>0.01–0.32</td>
</tr>
<tr>
<td>VA</td>
<td>0.11</td>
<td>0.05</td>
<td>0.07–0.37</td>
</tr>
<tr>
<td>VV</td>
<td>0.05</td>
<td>0.05</td>
<td>0.01–0.15</td>
</tr>
<tr>
<td>AV</td>
<td>0.04</td>
<td>0.05</td>
<td>0.01–0.27</td>
</tr>
<tr>
<td><strong>$d'$</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AA</td>
<td>3.36</td>
<td>0.94</td>
<td>0.91–4.65</td>
</tr>
<tr>
<td>VA</td>
<td>2.50</td>
<td>0.75</td>
<td>0.44–3.71</td>
</tr>
<tr>
<td>VV</td>
<td>3.54</td>
<td>0.96</td>
<td>1.44–4.65</td>
</tr>
<tr>
<td>AV</td>
<td>3.23</td>
<td>0.26</td>
<td>2.61–3.83</td>
</tr>
</tbody>
</table>

AA: auditory ipsimodal; VA: auditory crossmodal; VV: visual ipsimodal; AV: visual crossmodal.

For the schizophrenic group, auditory crossmodal discrimination ($d'$ in Table 2, visual to auditory = 2.50) is significantly lower than visual crossmodal discrimination (auditory to visual = 3.23). Both auditory (3.36) and visual (3.54) ipsimodal discrimination are significantly better than the corresponding crossmodal (visual to auditory = 2.50 and auditory to visual = 3.23) conditions. No difference was detected between auditory and visual ipsimodal conditions.

For the bipolar disorder group, a significant difference in $d'$ was detected between auditory and visual ipsimodal conditions with this group showing better discrimination of auditory

<table>
<thead>
<tr>
<th>Condition</th>
<th>Contrast</th>
<th>$r^2$</th>
<th>$P$</th>
<th>$r^2$</th>
<th>$P$</th>
<th>$r^2$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ipsimodal</td>
<td>AA–VV</td>
<td>−2.30</td>
<td>ns</td>
<td>2.60</td>
<td>&lt;.01</td>
<td>0.16</td>
<td>ns</td>
</tr>
<tr>
<td>Crossmodal</td>
<td>AV–VA</td>
<td>−7.95</td>
<td>&lt;.001</td>
<td>−9.19</td>
<td>&lt;.001</td>
<td>−39.43</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Ipsimodal/crossmodal</td>
<td>VV–AV</td>
<td>−5.45</td>
<td>&lt;.001</td>
<td>−1.65</td>
<td>ns</td>
<td>−2.30</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>AA–VA</td>
<td>−12.12</td>
<td>&lt;.001</td>
<td>−12.26</td>
<td>&lt;.001</td>
<td>−34.39</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

*a* Familywise error rates applied.

*b* Only descriptively meaningful comparisons were made: between two crossmodal conditions (AA–VV), between two ipsimodal conditions (AV–VA), and between auditory ipsimodal to auditory crossmodal (AA–VA) and visual ipsimodal to visual crossmodal (VV–AV).

$^c$ $df = 46$.

$^d$ $df = 41$.

$^e$ $df = 88$. 
ipsimodal stimuli. Auditory crossmodal (visual to auditory = 3.03) discrimination is significantly lower than visual crossmodal discrimination (auditory to visual = 3.70). There was no difference detected for visual ipsimodal (visual to visual = 3.80) compared to visual crossmodal (auditory to visual = 3.70) functioning. However, auditory ipsimodal functioning (3.90) was significantly better than auditory crossmodal auditory functioning (visual to auditory = 3.03).

The comparison group showed a significant lower auditory crossmodal (visual to auditory = 3.52) preference over visual crossmodal functioning (auditory to visual = 4.43). Additionally, auditory ipsimodal functioning (4.51) was better than auditory crossmodal functioning (visual to auditory = 3.52). No significant discriminatory differences were detected between auditory (4.51) and visual (4.50) ipsimodal functioning nor visual ipsimodal (4.50) and crossmodal (4.43) switching.

3.5. Difference scores

Based on the relatively depressed visual to auditory switching scores across all three groups, difference scores were calculated comparing auditory ipsimodal and crossmodal (auditory to auditory and visual to auditory) and visual ipsimodal and crossmodal (visual to visual and auditory to visual) functioning. Although the three groups were significantly different in terms of their mean auditory $d'$ responsivity, the magnitude of the difference was not statistically significant, $F(2, 175) = 1.66, ns.$ A significant main effect, however, was detected for the visual condition, $F(2, 175) = 7.38, P < .001, \eta^2 = .09.$ Bonferroni corrected post hoc analysis showed that the magnitude of visual to visual and auditory to visual difference was greatest comparing the schizophrenic group to the bipolar disorder group ($P < .01$) and the schizophrenic group and the comparison group ($P < .001$). No difference was detected between the bipolar disorder group and the comparison group.

3.6. Medication effects

At the time of testing, all patients were receiving medication. A thorough analysis of medication levels and test performance was conducted. No medication effects were detected across or within groups. This finding is consistent with other studies (Epstein, Keefe, Roitman, Harvey, & Mohs, 1996; Goldberg, Berman, & Weinberger, 1989; Liu, Chen, Chang, & Lin, 2000) that reported no significant interaction of neuroleptic medications on attention functioning.

4. Discussion

4.1. Response sensitivity in simple modal condition

The analyses of response sensitivity showed a differential pattern of modal response discrimination between groups. While the hit rate (86–89%) for patients with schizophrenia was

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2 This analysis is available on request.
higher than chance (50/50), this group was also two to three times more likely to commit errors of commission than the comparison group. Moreover, these patients committed significantly more auditory errors of omission and commission than visual errors in either category. This combined pattern of modal specific errors resulted in a visual over auditory response preference for subjects with schizophrenia.

Patients with bipolar disorder also displayed a modal response differential but it was in the opposite direction and much more specific than that of patients with schizophrenia. Unlike the schizophrenic group, patients with bipolar disorder showed no difference between auditory and visual commission error rates. However, this latter group did commit more visual errors of omission than auditory errors of omission. This modal specific reduction in responses produced an auditory over visual response preference for this group.

### 4.2. Response bias

Both research groups showed a tendency, in mean $L_x$ scores, to be more liberal in their responding patterns than did the comparison group. These groups had a propensity to be more impulsive shown in over-responding. The comparison group tended to be more conservative in response style. The correlations between response discrimination and bias indices suggested a weak negative correlation for both research groups with a tendency for sensitivity to improve for those subjects who showed a neutral response bias, neither over- or under-responding. For schizophrenic subjects this tendency was linear, however, for bipolar subjects there was a curvilinear trend in the relationship of sensitivity and bias. It does appear that response bias in the research groups affected response sensitivity, though the relationship is weak. That there is a general trend in both groups for discrimination to improve as response bias become more neutral, that is, less impulsive, does suggest that amelioration of over-responding tendencies may improve sensitivity to stimulus discrimination.

The comparison group showed a moderate to strong positive correlation between their sensitivity and bias indices. Not unlike the research groups, their sensitivity improved (especially in the visual condition) for subjects who adopted a neutral response bias.

These findings suggest that those individuals who adopted a more liberal response bias, that is, more impulsive responding, also displayed poorer response sensitivity. Moreover, there is a weak to moderate relationship for response sensitivity to improve as individuals across each group treated the targets and foils more alike. Put otherwise, participants tended to treat targets and foils more similarly over time and consequently responded more discriminately.

As expected, no modal differences were detected in response bias across any of the groups. This finding is most likely an artifact of the measure and the intermixed presentation of auditory and visual stimuli.

### 4.3. Response sensitivity in modal switching conditions

In terms of ipsimodal and crossmodal response patterns there were mixed results. In the analysis of visual ipsimodal and crossmodal conditions, only the schizophrenic group showed significantly lower response sensitivity to visual crossmodal stimuli compared to visual ipsimodal stimuli. Neither the bipolar disorder group nor the comparison group showed any
reduction in response sensitivity when visual ipsimodal $d'$ was compared with the visual crossmodal $d'$.

By comparison to the auditory and visual ipsimodal and visual crossmodal switching each of the groups showed the poorest response sensitivity in the auditory crossmodal switching condition. Similar findings have been reported by Sutton et al. (1961), Benton et al. (1962), and Mussgay and Hertwig (1990). The study groups committed more false alarms in this condition than any other which resulted in depressed auditory crossmodal $d'$ scores. In other words, when a visual target preceded an auditory foil then individuals had a greater tendency to respond by pushing the mouse button. It cannot be the situation that a visual stimulus primes the subject to respond since false alarm rates in the visual ipsimodal condition are not significantly different than either auditory ipsimodal or visual crossmodal conditions for the normal comparison group. Nor can it be the case that the crossmodal shift creates a startle response since the visual crossmodal $d'$ scores are significantly higher than the auditory crossmodal $d'$ scores for each group (cf. Table 3).

The analysis of difference scores provides a possible explanation for what is occurring. Even though auditory ipsimodal and crossmodal sensitivity are statistically different, there was no significant variation in the difference scores across groups. If difference scores are used as a crude indicator of task demand, for example, the amount of effort required for switching between two auditory stimuli versus the amount of effort required to switch from a visual stimulus to an auditory stimulus, then there is no difference between actual task demands across the three groups. For example, the comparison group's difference score in the auditory ipsimodal–crossmodal comparison ($M = 0.99$) is 14 times greater than the reciprocal visual ipsimodal–crossmodal comparison difference score ($M = 0.07$). In fact, it appears that auditory crossmodal switching is a different task than any of the other conditions. Moreover, this condition does not discriminate among the three groups. The visual ipsimodal–crossmodal condition, however, did differentiate the bipolar group from the schizophrenic group.

When a visual target appears first it is much more difficult to inhibit responding to an auditory foil, which in turn, increases the probability of committing an error of commission. As reported by Baerwald et al. (2001), this specific condition resulted in longer RT latencies compared to any other condition. Not only does it take an individual longer to respond to this crossmodal condition but also the response has a higher probability of being wrong. This specific pattern of false alarm rates across all groups suggests that the serial presentation of a visual stimulus followed by an auditory stimulus results in a stronger neural trace that makes the discrimination of signal from noise much more difficult.

5. Conclusions

This study found that a potential discriminator between patients with schizophrenia and patients with bipolar disorder is the direction of modal response sensitivity. Patients with schizophrenia showed statistically higher $d'$ indices, that is, better discriminability, to visual stimuli. This finding held in both the analyses of simple modal responding as well as ipsimodal responding. Conversely, patients with bipolar disorder displayed better sensitivity to auditory
stimuli. Visual to auditory crossmodal shifting resulted in severely depressed $d'$ scores for all groups and is therefore not a reliable discriminator.

The results of test bias analyses indicated that the two study groups adopted a more liberal, or impulsive, test-taking attitude. In general, these groups required less information before deciding if a stimulus was a target or a foil. The $d'$ indices, for all groups, showed a weak to moderate correlation with response bias; the general tendency was for $d'$ scores to improve as participants treated target and foil stimuli more alike.

Two potential limitations of this study were the use of a normal comparison group and not controlling for subject diagnosis with the use of a structured clinical interview. The use of a normal comparison group may have overestimated the magnitude of differences when compared to the study groups. However, since the overall findings of this study reflect those detected by Mussgay and Hertwig (1990) using a control group, it is not believed that the current results would be substantially different. Secondly, the lack of a structured diagnostic procedure for subject group inclusion may have caused some confound between groups. While stringent controls were used to reduce diagnostic overlap, the possibility of diagnostic heterogeneity cannot be ruled out. Nonetheless, caution is warranted in the generalizability of these findings.

A clear direction for future research on bimodal response sensitivity is to further examine the perceptual and cognitive demands of the auditory crossmodal shifting conditions. The findings of this study, along with those reported by Mussgay and Hertwig (1990), report depressed sensitivities across all groups, including normal comparison group, in this condition. It is thought that such a study may provide greater understanding of the cognitive and perceptual demands of crossmodal shifting.

References


