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Normal Time Course of Auditory Recognition in Schizophrenia, Despite Impaired Precision of the Auditory Sensory ("Echoic") Memory Code

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Prior studies have demonstrated impaired precision of processing within the auditory sensory memory (ASM) system in schizophrenia. This study used auditory backward masking to evaluate the degree to which such deficits resulted from impaired overall precision versus premature decay of information within the short-term auditory store. ASM performance was evaluated in 14 schizophrenic participants and 16 controls. Schizophrenic participants were severely impaired in their ability to match tones following delay. However, when no-mask performance was equated across participants, schizophrenic participants were no more susceptible to the effects of backward maskers than were controls. Thus, despite impaired precision of ASM performance, schizophrenic participants showed no deficits in the time course over which short-term representations could be used within the ASM system.

Schizophrenia is a severe mental illness associated with information-processing deficits that may represent a core feature of the disorder. One system that has recently been shown to be dysfunctional in schizophrenia is the auditory sensory ("echoic") memory system, which maintains short-duration representations of the simple physical characteristics of auditory stimuli (e.g., pitch, intensity). Functioning of the echoic memory system is indexed behaviorally by the ability of participants to match tones following brief delay (Cowan, 1984, 1988) and electrophysiologically by generation of a specific event-related potential termed *mismatch negativity* (Cowan, Winkler, Teder, & Naatanen, 1993; Ritter, Deacon, Gomes, Javitt, & Vaughan, 1995; Winkler, Reinikainen, & Naatanen, 1993). Schizophrenic participants show severe deficits in both tone-matching performance (Holcomb et al., 1995; Javitt, Strous, Grochowski, Ritter, & Cowan, 1997; Strous, Cowan, Ritter, & Javitt, 1995) and mismatch negativity generation (Catts et al., 1995; Javitt, Doneshka, Grochowski, & Ritter, 1995; Javitt, Doneshka, Zylberman, & Ritter, 1993; Oades, 1994; Shelley, Ward, Catts, & Michie, 1991; Shutara et al., 1996), indicating severe deficits in functioning of the auditory sensory memory system.

On the basis of prior research with normal participants, it has been proposed that the auditory sensory memory system possesses two distinct phases (Cowan, 1984). The first is a *short auditory store,* with a duration of 200–300 ms. The second is a *long auditory store* (Cowan, 1984), with a duration of up to several tens of seconds. Both the short and long auditory stores, which together comprise the auditory sensory or echoic memory system, maintain representations primarily of the simple physical characteristics of presented stimuli such as pitch, loudness, or timbre. However, the two components have different roles in the flow of auditory information processing (Cowan, 1984, 1988; Massaro, 1972, 1975). Following stimulation, representations of the physical attributes of stimuli are initially maintained in the short auditory store. During the 200–300 ms that such representations are maintained within the short store, information is progressively extracted into the long auditory store. Information within the short store appears to be maintained in a labile form. Thus, when a brief target stimulus is presented in a recognition task and is followed closely by a second stimulus with similar physical properties, the recognition of the target is impaired, leading to the phenomenon of *backward masking.* As the interval between the onset of the target and the onset of the mask increases, there is a gradual release of masking so that target recognition reaches an asymptotically high level of performance within a few hundred milliseconds. It is assumed that the mask harms recognition of the target by inter-

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rupting the process of extraction of featural information concerning the target from the short- to the long-term store. However, it is not totally clear if the disruption occurs because the short auditory trace of the target is overwritten (Massaro, 1972), because there is some integration of the features of the target and mask (Crawley, Kallman, & Neely, 1994; Massaro, 1972; Massaro & Idson, 1977; Sparks, 1976), or because the mask draws attention away from processing of the target (Hawkins & Presson, 1977; but see Kallman & Morris, 1984). Nevertheless, auditory backward masking is an extremely robust and reproducible phenomenon. Tone-recognition performance is near chance when the tone to mask interval is short (<40 ms) and rises to an asymptotic level as the tone to mask interval increases to about 250 ms (Kallman & Massaro, 1979; Massaro, 1970).

Once featural information is extracted from the short auditory store, such information can be maintained and synthesized within the long auditory storage for several tens of seconds, over which time it decays, apparently exponentially. Each new sound presented within a sequence only partially interferes with the long auditory representation of the previous sound. Thus, as opposed to the short auditory store, the long store may be capable of maintaining separate representations of several individual sounds. Integrity of the long auditory store can be evaluated effectively using stimulus recognition tasks, such as tone matching. If deficits are detected in a tone-matching task, however, it cannot be determined whether the deficits are due to intrinsic dysfunction within the long auditory store or to impaired transfer of information from the short auditory store.

To date, studies conducted on auditory memory processing in schizophrenia have focused primarily on processing, once information has been extracted to the long auditory store. In prior studies it has been demonstrated that the precision of processing in schizophrenia is decreased by the time that information has entered the long store (i.e., about 300 ms; see Strous et al., 1995). It has also been demonstrated that retention and rate of loss of information within the long store is normal (Javitt et al., 1997). Thus, although the precision of auditory information processing is impaired, the deficit does not appear to be due to impaired retention of information within the long auditory store. The present study, therefore, investigates the degree to which deficits in information retention within the short store may contribute to the overall deficits in auditory processing precision in schizophrenia.

Functioning of the short auditory store is investigated using auditory backward masking, which permits evaluation of the time course of information transfer from the short to the long auditory store. If two groups of participants differ in the shapes of their backward-masking functions, despite an adequate control for psychometric properties of the data (such as the level of overall performance; Chapman & Chapman, 1978), then it can be assumed that the groups differ in some aspect of information extraction. The difference can be either in the duration of their short-duration auditory storage, which limits the time during for which information can be extracted, or in the rate at which information actually is extracted from this short-duration store. However, if it can be shown with adequate precision that there is no difference in the masking functions of two groups, then it can be said that their rates of information extraction are the same or similar and that both groups have a short auditory store that persists for at least as long as masking is found to continue. Using detailed analysis of backward-masking curves, Massaro and Burke (1991) showed that 8-year-old children and adults do not differ in their rates of information extraction, although 8-year-olds are less accurate than adults in the tone-matching task. In contrast, elderly participants have been found to have slowed rates of feature extraction, despite equivalent tone-matching performance (Newman & Spitzer, 1983). Thus, functioning of the short auditory store can be evaluated independent of the functioning of the long store, and the pattern of results observed in schizophrenic participants can be compared with the pattern observed in other groups of participants.

Method

Participants

Informed consent was obtained from 14 chronic schizophrenic inpatients and 16 nonpsychiatric comparison participants of similar age (patients = 39.6 ± 8.9 years; controls = 39.2 ± 7.0 years). All of the participants were of normal hearing by self-report. Participants with significant musical training were excluded. Schizophrenic participants were recruited from the inpatient units of the Bronx Psychiatric Center, a New York State inpatient treatment setting, and diagnosed according to criteria from the *Diagnostic and Statistical Manual of Mental Disorders* (3rd ed., rev.; *DSM–III–R*; American Psychiatric Association, 1987) by a board-certified attending research psychiatrist using semistructured clinical interview (*DSM–III–R* checklist) and other clinical materials as required. Participants with *DSM–III–R* Axis I disorders other than schizophrenia, including alcoholism or substance abuse, were excluded from the study. All but one patient were on antipsychotic medication at the time of testing (this patient had been prescribed haloperidol but was noncompliant with medication at the time of testing). Of these, 5 were receiving typical antipsychotics and 8 were receiving atypical antipsychotics (2 clozapine, 2 risperidone, 3 sertindole, and 1 seroquel); 4 participants were receiving additional treatment with anticholinergics, 2 were receiving valproate, 1 was receiving lithium, and 1 was receiving fluoxetine. Control participants were recruited by personal contact from faculty, trainees, and staff of the Bronx Psychiatric Center. The schizophrenic and control groups differed significantly in sex distribution, with more women included among the controls (6 men, 10 women) than among the patients (12 men, 2 women). Control participants were also significantly higher than patients in the Quick Test (Ammons & Ammons, 1962; IQ: patients = 96.9 ± 10.2, controls = 110.7 ± 14.4), $t(26) = 2.9$, $p < .01$. All of the participants received a small honorarium for their participation.

Design

Tone-matching ability was assessed first with minimal between-tone delay, then with a 500-ms between-tone delay, and finally with a mask following the second tone. All of the tones in the study were generated using the Neuroscan (Herndon, VA) STIM system implemented on a personal computer and delivered through earphones at 75 dB SPL nominal intensity.

For minimal delay testing, tones consisted of 200-ms composites made up of an initial 100-ms segment of one pitch and a final 100-ms segment of either the same or different pitch. Tones were at the zero crossing at the point of juncture. A taper (10-ms rise/fall) was applied to the composite stimulus. Blocks of 20 stimuli each were presented. In each block, the degree of pitch deviance was held constant. For one half of the stimuli within each block, the final and initial segments were identical (*same* trials). For the remaining one half, the final segment differed by a fixed percentage from the initial segment (*different* trials). After each stimulus, the participant was asked to respond verbally as to whether the stimulus sounded like one long tone of invariant pitch (same) or whether the pitch appeared to change in the middle (different). For each block, total correct responses, number of false-positive responses, and number of false-negative responses were recorded. Testing was initiated at the easiest level and proceeded to progressively more difficult levels until participants were no longer able to achieve a score of 80% (16/20) correct responses. The most difficult level at which an individual participant was able to perform with 80% or greater accuracy was considered his or her tone-matching threshold. Level of task difficulty was determined by the pitch difference (Δf) between the initial and final segment of each stimulus. For all stimuli, the initial segment consisted of a 1000-Hz tone. Levels of difficulty were 40%, 20%, 10%, 7.5%, 5%, 2.5%, 2%, and 1%, corresponding to final segments of 1400, 1200, 1100, 1075, 1025, 1020, and 1010 Hz.

Delayed tone matching was assessed using a similar procedure, except that tapers (10-ms rise/fall) were applied to each 100-ms segment individually and the two segments were separated by a 500-ms intertone interval. For both minimal delay and 500-ms delay testing, intertrial interval was 5 s.

Once threshold had been determined for each participant, effects of backward masking were assessed. The backward-masking stimulus consisted of a 100-ms composite tone constructed by superimposing the 1000-, 1020-, 1025-, 1050-, 1075-, 1100-, 1200-, and 1400-Hz stimuli used for threshold determination. Backward masking for each participant was tested at that participant's individually determined threshold. For assessment of backward masking, stimuli were presented in four blocks containing 28 trials each. Each trial consisted of reference and test tones separated by 500 ms, followed by the backward masker presented at a variable interval following the test tone. In one half of the trials, the reference and test tones were the same; in the remaining one half, they differed by the fixed level of Δf. Seven levels of test-tone–mask interval were used (0, 20, 40, 80, 160, 250, and 500 ms). Test-tone–mask interval varied in pseudorandom order within and across each of the four blocks. The number of correct versus incorrect responses was recorded at each delay interval, and incorrect responses were further subdivided into false positives (responding *same* when reference and test stimuli were different) and false negatives (responding *different* when reference and test stimuli were the same).

Statistics

Between-groups differences in performance were analyzed using repeated measures analyses of variance (ANOVAs; SPSS for Windows, SPSS, Chicago; Norusis, 1994) with a within-group variable of interstimulus interval (ISI; 0, 20, 40, 80, 160, 250, and 500 ms) and a between-groups variable of diagnostic group (control vs. schizophrenic). Threshold values were normalized by log transformation prior to analysis. Multivariate F tests equivalent to Wilks's lambda were used to assess repeated measures effects (Harris, 1985). Signal detection indices were calculated as per Grier (1971). Estimated effect sizes (partial η^2) and likelihood of false-negative response (β) for an assumed alpha level of $p < .05$ were determined using SPSS 7.0 for Windows. Power analyses were performed using the Power and Precision program (Biostat, Teaneck, NJ; Borenstein, Rothstein, & Cohen, 1997) with an assumed alpha level of $p < .05$.

Results

As shown in Figure 1, schizophrenic participants were severely impaired in their ability to match tones across both the minimal delay and 500-ms delay no-mask conditions, $F(1, 28) = 25.9, p < .0001$. There was an expected, highly significant across-groups effect of delay, such that both groups performed with lower accuracy in the 500-ms than in the minimal delay condition, $F(1, 28) = 24.8, p < .0001$. The Group × Delay interaction, in contrast, was not significant, $F(1, 28) = 1.5, p > .2$, reflecting the fact that schizophrenic participants were no more affected by delay than were control participants during the transition from a minimal delay to a 500-ms delay condition. Tone-matching thresholds were significantly greater for schizophrenic than for control participants in both the minimal delay, $F(1, 28) = 13.5, p < .005$, and 500-ms delay, $F(1, 28) = 25.4, p < .0001$, conditions. In the minimal delay condition, schizophrenic participants required a difference of 95.0 ± 106.2 Hz to perform at threshold versus 25.0 ± 15.8 for controls, $t(28) = 2.44, p < .03$. In the 500-ms delay condition, schizophrenic participants required a difference of 194.6 ± 127.9 Hz to perform at threshold versus 52.8 ± 59.7 Hz for control participants, $t(28) = 3.89, p < .001$. Expressed in ratio terms (given a 1000-Hz standard stimulus), in the minimal delay condition, schizophrenic participants needed an approximately 5%

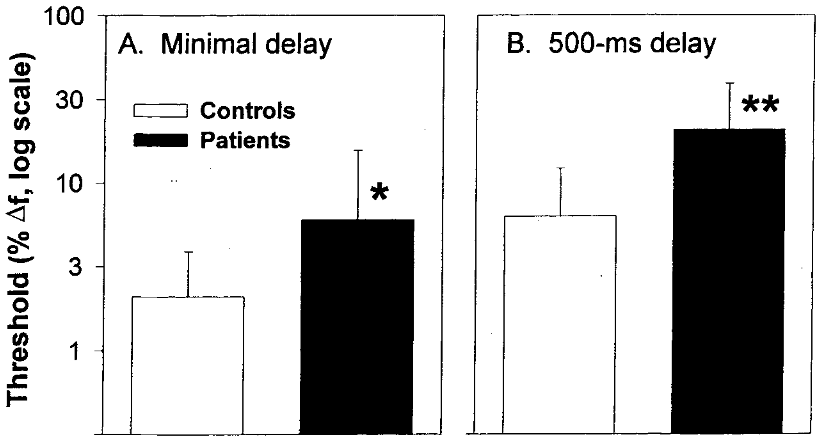

Figure 1. Tone-matching threshold for control and schizophrenic participants in the no-mask condition when intertone interval was either minimal or 500 ms. Threshold was determined as the minimal ratio between test and reference tone, expressed as percentage difference in pitch Δf, at which participants were able to obtain a performance level of 80% of greater correct responses. All comparisons were based on a base tone of 1000 Hz. Comparison tones were 1010, 1020, 1025, 1075, 1100, 1200, or 1400 Hz in pitch, corresponding to Δf levels of 1, 2, 2.5, 5, 7.5, 10, 20, and 40%. Values are $M \pm SD$ across participants within each group. $*p < .005$; $**p < .001$ vs. control.

between-tone pitch difference to perform as well as controls at 2% Δf. In the 500-ms delay condition, schizophrenic participants required an approximately 20% difference in pitch to perform as well as controls, with a 5% difference (Figure 1). Using a 10% Δf threshold (i.e., 1000-Hz vs. 1100-Hz tones) in the 500-ms delay condition, it was possible to correctly categorize 10 of 14 schizophrenic participants (71%) and 14 of 16 control participants (88%; Fisher exact test, $p = .004$).

Susceptibility to backward masking was assessed on the basis of the percentage of correct responses (correct detection + correct rejections), with each participant performing at an individually determined level of Δf. Masking was tested at seven levels of ISI. Across participants, there was a highly significant effect of ISI, $F(6, 23) = 10.3, p < .001$, indicating progressively greater effectiveness of the mask as ISI was decreased from 500 to 0 ms (Table 1). There was, however, no significant between-groups difference, $F(1, 28) = 0.5, p = .5$, and, critically, no significant Group × ISI interaction, $F(6, 23) = 0.6, p = .8$. Furthermore, there were no significant between-groups differences in performance level at any of the seven levels of ISI considered individually. Thus, despite the effectiveness of the mask, schizophrenic participants were no more susceptible to backward masking than were control participants.

Statistical power analysis (Cohen, 1988) was performed to determine the degree to which the absence of a significant group effect and Group × ISI interaction might be due to lack of statistical power. For both analyses, the likelihood of a false-negative result, based on the observed data distribution, was ≤ 0.2. Furthermore, to the extent that there was a between-groups difference in susceptibility to backward masking, the degree of difference was statistically small. For the Group × ISI effect, the estimated effect size was 0.13; for the main effect of group, the estimated effect size was 0.02. These values fall in the neighborhood of 0.1, which is considered the defining value for small effect size. By way of comparison, the estimated effect size for the between-groups difference in delayed tone-matching threshold was 0.48, which is above the threshold for a large effect (0.4). In the backward-masking paradigm, the estimated effect size for the main effect of ISI was 0.73, which is also extremely large. On the basis of sample size alone, the power of this paradigm for detecting a between-groups difference for effect sizes in the range of 0.48 to 0.73 is between 0.72 and 0.97. Thus, the absence of a between-groups difference in susceptibility to backward masking cannot easily be attributed to lack of statistical power.

Table 1
Percentages of Correct Detections and False Alarms (M ± SD) on Tone Matching During the Backward-Masking Task as a Function of Tone–Mask Interval (ISI; in Milliseconds).

	Correct detections		False alarms	
ISI	Controls	Schizophrenics	Controls	Schizophrenics
0	40.6 ± 31.1	45.5 ± 27.6	38.5 ± 34.0	42.3 ± 33.2
20	50.8 ± 27.9	50.0 ± 31.0	29.4 ± 21.8	40.7 ± 26.4
40	51.6 ± 27.7	61.6 ± 29.6	34.9 ± 26.7	42.8 ± 32.8
80	72.7 ± 25.1	68.8 ± 25.4	41.0 ± 30.8	39.8 ± 33.9
160	78.1 ± 25.2	82.1 ± 22.8	38.8 ± 27.1	46.2 ± 32.0
250	83.6 ± 20.8	76.8 ± 24.4	37.4 ± 30.7	35.8 ± 26.9
500	85.9 ± 15.7	81.3 ± 25.8	37.1 ± 26.9	33.8 ± 31.5

Note. For all participants, testing was performed using individually determined between-tone levels of pitch difference that yielded a no-mask performance level of ≥ 80% correct. Chance performance level was 50%.

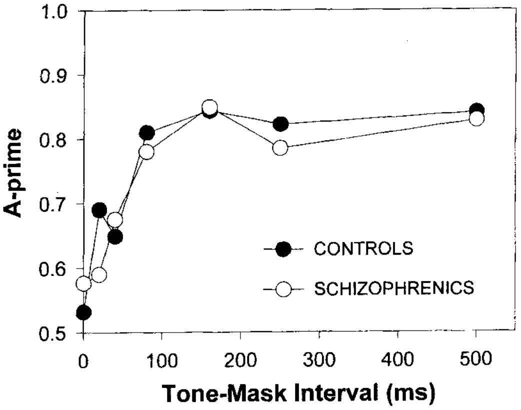

Figure 2. Sensitivity of auditory tone matching as a function of tone–mask interval. A′ values were calculated as per Grier (1971).

Because there were significantly more female participants in the control group than in the experimental group, data were reanalyzed only for male participants. As for the whole group, there was a significant main effect of ISI, $F(6, 11) = 6.5, p = .004$, but no main effect of group, $F(1, 16) = 0.7, p = .4$, or Group × ISI interaction, $F(6, 11) = 0.5, p = .8$. Also, within the control group, there was no main effect of sex, $F(1, 14) = 0.3, p = .6$, or Sex × ISI interaction, $F(6, 9) = 0.2, p = .98$. Finally, when sex was included as a variable in the between-groups analyses, there was no significant main effect of sex, $F(1, 26) = 0.2, p = .7$ or Sex × Group interaction, $F(1, 26) = 0.1, p = .8$. Sex × Delay, $F(6, 21) = 0.5, p = .8$, and Sex × Group × Delay interactions, $F(6, 21) = 0.8, p = .6$, were also nonsignificant. In contrast, significant between-groups differences were observed in no-mask threshold, even when data were reanalyzed to include only male participants, $F(1, 16) = 14.0, p = .002$. As for the group as a whole, there was a highly significant effect of delay, $F(1, 16) = 10.2, p = .006$, but no significant Group × Delay interaction, $F(1, 16) = 1.36, p = .3$. Finally, when sex was included as a variable in the overall between-groups analyses, the main effect of diagnostic group remained strongly significant, $F(1, 26) = 10.6, p = .003$. No main or interactive effects involving sex were significant.

Other potential sources of a false-negative result (lack of Group × ISI effect in backward masking) were also explored. Schizophrenic and control participants did not differ in the number of false-positive or false-negative responses considered separately, indicating similar strategies across groups. When signal detection analyses (Grier, 1971) were performed, mean sensitivity (A′, shown in Figure 2) and bias measures were not different across groups. Although the groups differed in IQ, there were no significant correlations between IQ and either tone-matching threshold or performance during backward masking. Furthermore, treating IQ as a covariate in the statistical analyses did not significantly alter the results of the study. Participants receiving anticholinergics performed somewhat better than those who did not receive anticholinergics, $t(28) = 2.07, p = .06$. The between-groups difference in minimal delay, $F(1, 24) = 18.0, p < .0001$, and 500-ms delay, $F(1, 24) = 30.4$, $p < .0001$, tone-matching performance remained highly significant, even when participants on anticholinergic medication were excluded and the Group × Delay interaction remained nonsignificant, $F(6, 19) = 0.4$, $p < .9$.

Finally, in order to exclude the possibility of tone-discrimination threshold shifts during the testing session, due, potentially, to fatigue, the final 17 participants in the study were retested for threshold following the conclusion of the backward-masking trials (this procedure was not implemented until after the initial 13 participants had already been tested). The 17 participants who were retested (9 control and 8 schizophrenic participants) showed the same level of performance following completion of the backward-masking testing as they had during the initial testing. Control participants showed a log-transformed 500-ms delay threshold of 1.59 ± 0.34 at the beginning of the testing session, compared with a level of 1.43 ± 0.21 at the end of testing. Schizophrenic participants showed an initial level of 2.3 ± 0.11 prior to testing versus a level of 2.3 ± 0.10 at the end of testing. A repeated measures ANOVA demonstrated the lack of a significant session (test vs. retest) effect, $F(1, 15) = 1.4$, $p > .2$, or Group × Session interaction, $F(1, 15) = 1.4, p > .2$. Furthermore, even in the limited sample, the between-groups difference in tone-matching threshold was highly significant, $F(1, 15) = 39.4$, $p < .001$.

Discussion

Information-processing deficits in schizophrenia span multiple sensory domains, but effects of backward masking have to date been confined to the visual system. This is the first study to assess auditory backward-masking performance in schizophrenia. There are two major findings of this study: First, auditory sensory memory performance is severely impaired in schizophrenia, reflecting significantly decreased precision of auditory processing. Second, when adjustment is made for the overall decrease in precision of processing, schizophrenic participants are no more susceptible to auditory backward masking than are control participants. Schizophrenic participants had equivalent levels of deficit in the minimal delay and 500-ms delay conditions, supporting earlier findings that the deficit in performance in the auditory sensory memory task is not due to a deficit in maintaining the sensory memory trace (Javitt et al., 1997). Rather, it suggests that the impaired performance of the task reflects an inability either to form a precise representation of the presented stimulus or to use such a representation to perform the required tone-matching task. Although the present investigation involves only the auditory system, the inability to form or use precise stimulus representations might contribute to impaired performance in any task that depends on formation and utilization of short-duration mnemonic traces. In fact, deficits have been observed in other systems requiring formation and utilization of highly precise, modality-specific information (Fleming et al., 1997; Keefe et al., 1995). The finding of impaired auditory sensory memory in schizophrenia supports recent reports in which sensory memory performance was assessed at fixed, predetermined levels of Δf (Holcomb et al., 1995; Javitt et al., 1997; Strous et al., 1995). For the present study, a staircase procedure was used to prevent floor–ceiling effects. Participants started at a fixed level of Δf, and task difficulty was progressively adjusted in accordance with ongoing performance. Using this approach, we again observed a highly robust deficit in auditory sensory memory performance, such that 80% of the participants could be correctly identified on the basis of delayed tone-matching ability alone.

Despite their severe deficit in auditory sensory memory performance, schizophrenic participants were no more susceptible to backward masking than were control participants. In both groups, the masking stimulus produced an exponentially decreasing level of performance with decreasing ISI. Moreover, over the interval of 0 to 500 ms, performance in both groups ranged from near chance to a level similar to that observed in the no-mask condition. Thus, the absence of a deficit cannot be attributed to psychometric insufficiency on the part of the masking stimulus. The finding that auditory backward-masking performance is not impaired in schizophrenia indicates that information extraction from the short store of auditory sensory memory is no slower in schizophrenic than in control participants. The present study, along with earlier work (Javitt et al., 1997), suggests that the primary deficit in auditory processing in schizophrenia relates to the precision with which sensory features such as pitch can be represented or used in the auditory sensory memory system, rather than the rate at which information can be extracted from the short auditory store or the duration over which such information can be retained.

In contrast to the present study on auditory backward masking, there have been several reports of impaired visual masking performance in schizophrenia (Braff, 1993; Green, Nuechterlein, & Mintz, 1994; Weiss, Chapman, Strauss, & Gilmore, 1992). Further studies are needed to determine whether the differential results reflect differential auditory versus visual processing deficits in schizophrenia or whether the differences are due to differences in experimental design. One possible explanation is that the present paradigm used relatively simple stimuli without intrinsic meaning, whereas most visual backward-masking tasks have been performed with inherently meaningful stimuli, such as letters. Relatively normal backward-masking functions and iconic memory performance have been observed in some studies in which relatively simple stimuli were used (Knight, Elliott, & Freedman, 1985; Knight, Shere, Putchat, & Carter, 1978). It has also been reported that schizophrenic patients can detect meaninglessness as quickly as can control participants but are slower in detecting meaningfulness (Knight, 1992). Furthermore, it has been reported that schizophrenic patients are impaired in using top-down factors such as categorization to segregate information in the auditory stream (Silverstein, Matteson, & Knight, 1996). The present findings are consistent with the event-related potential finding that processing of a visual target is impaired in schizophrenia even prior to the introduction of a mask (Patterson, Spohn, Bogia, & Hayes, 1986).

Several limitations of the present study must be considered. First and foremost, all of the participants in the present study were receiving antipsychotic medication and several were receiving anticholinergic medication, compared with the fact that none of the control participants were taking medication. It is possible, therefore, that the deficit in tone-matching performance is due to medication effect. It is also possible that neuroleptics may have "normalized" the backward-masking performance of schizophrenic participants, especially as antipsychotics have been found to reduce, rather than increase, between-groups differences in visual backward masking performance (Saccuzzo, Cadenhead, & Braff, 1996). Anticholinergics did not appear to be a factor, as participants on anticholinergics, if anything, performed better than those who were not on anticholinergics. Moreover, the between-groups statistics remained unchanged when participants on anticholinergics were excluded from the analyses. The control group also contained more women than did the experimental group, and the IQ level of the control participants was higher than that of the patients. However, no between-sex differences in performance were found within the control group, and using either sex or IQ as a covariate did not substantially affect the statistical results of the study.

Finally, results of the present study can be compared with studies of auditory backward-masking performance in aging (Newman & Spitzer, 1983). Elderly participants have similar levels of performance when the tone to mask interval is long, but perform less accurately than do young participants at intervals below 360 ms, reflecting an age-associated slowing of information extraction from the short auditory store. The lack of deficit in backward-masking performance in schizophrenic participants therefore suggests that auditory processing impairments in schizophrenia are substantially different from those that occur as a consequence of aging. The fact that increased susceptibility to auditory backward masking can be observed in some clinical situations indicates that the paradigm is sensitive to some forms of brain dysfunction. The fact that a deficit was not observed in schizophrenia supports the concept that auditory processing speed is not slowed, although precision is impaired.

In summary, despite extensive literature on susceptibility to visual backward masking in schizophrenia, susceptibility to auditory backward masking has not previously been evaluated. As in prior studies, schizophrenic participants were found to require a far larger pitch difference than control participants in order to differentiate two tones presented with a short intervening delay. However, schizophrenic participants were no more susceptible to auditory backward masking than were control participants when tested at levels of between-tone pitch difference that yielded equivalent performance in the absence of a mask. These findings, along with prior investigations of auditory sensory memory performance in schizophrenia, indicate that whereas precision of processing within the auditory system is impaired, retention of information within the short- and long-term auditory stores is relatively unaffected by the disorder.

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