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BRIEF REPORT

Increased Stress Responsivity in Schizotypy Leads to Diminished Spatial Working Memory Performance

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Past research has emphasized the association between stress and the manifestation of psychotic symptoms in schizophrenia, yet relatively little is known about how environmental stressors affect cognitive processes in the illness. The present study sought to determine the effects of a loud noise stressor on a range of cognitive tasks, including spatial working memory (SWM), short-term visual memory, and sustained visual attention. Twenty-nine (29) schizotypic subjects and 45 controls performed the cognitive tasks across four waves of data collection: baseline, a noisy stress condition, and two follow-up conditions. Heart rate (BPM) was measured at each wave and subjective ratings of stress were collected in response to the loud noise stressor. Schizotypic subjects exhibited significantly greater increases in BPM during the loud, noisy stressor in comparison to controls. Additionally, schizotypic subjects' subjective ratings of stress in response to the loud noise were significantly greater than the controls' ratings. As hypothesized a priori, schizotypic subjects experienced significant decreases in SWM from baseline to the noisy stress condition in comparison to controls. Performance on non-SWM cognitive tasks did not significantly differ during the noisy stress condition and SWM performance did not significantly differ during noise-free conditions. Results from the present study highlight SWM as being particularly susceptible to loud noise stressors in a schizotypic population. Although the source of the induced impairment is not clear, one possibility is that the encoding stage of SWM was negatively affected by the loud noise.

Keywords: schizotypy, schizotypal, working memory, stress, endophenotype

The role of environmental stressors as well as nonschizophrenia-related genetic factors and epigenetic factors in the development from unexpressed schizotypy to schizophrenia has been discussed extensively by Lenzenweger (2010). Schizotypy refers to a latent personality organization that harbors the liability for schizophrenia, though only some persons with schizotypy go on to psychotic illness. It is likely that some measure of individuals who possess schizotypy will manifest this through overt clinical expression of the *DSM* cluster A personality disorders (schizotypal, paranoid, and schizoid; see Chapman, Chapman, Kwapil, Eckblad, & Zinser, 1994; Lenzenweger & Loranger, 1989b). Behavioral and biological data suggest that stress exacerbates psychotic symptoms and, over time, may even lead to the manifestation of psychosis. Observations of stress sensitivity in schizophrenia fit the diathesis-stress model (Monroe & Simons, 1991; Zuckerman, 1999), as lifetime stress predicts both the emergence and relapse of symptoms (Doering et al., 1998; Norman & Malla, 1993). These findings suggest that increased stress sensitivity is a focal concern among this population—those potentially at risk for schizophrenia and schizotypic pathologies—it may influence the manifestation of psychotic symptoms. This study examined the relationship between stress responsivity and neuropsychological functioning in relation to schizotypy in young adults with no prior history of psychosis. Understanding the effects of common stressors on neuropsychological functioning will help illuminate the process by which schizotypic subjects might decompensate into schizophrenia, thus aiding in detection of at-risk individuals.

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The Relationship Between Arousal and Cognition in Schizophrenia

Since schizotypic subjects—those who harbor a putative schizophrenia liability—appear to be more reactive to environmental stressors in their psychological functioning, their attentional resources, which are known to be impacted by stress, are more likely to be negatively impacted by stress than the general population.

Such problematic alterations in attention have the potential to affect performance on a broad range of cognitive tasks (Kahneman, 1973). As hypothesized in the current paper and elsewhere, (Cornblatt & Keilp, 1994; Dawson & Schell, 2002; Gjerde, 1983; Nuechterlein & Dawson, 1984; Schell & Dawson, 2005) individuals along the schizophrenia spectrum are more likely than controls to exhibit diminished cognitive performance when both groups are presented with the same environmental stressor. The goal of this study was to test this hypothesis by examining spatial working memory (SWM) performance among schizotypic subjects during the presence of a noisy-stress stimulus (see also Liston, McEwen, & Casey, 2009; Qin, Hermans, van Marle, Luo, & Fernández, 2009); if schizotypic subjects are hyper-responsive to stress, then their SWM ability should diminish in the presence of the noisy-stressor, whereas controls will show nonsignificant alterations. As a complex cognitive task, SWM is more likely to be impacted by stress-induced changes in autonomic arousal, whereas simpler cognitive tasks (e.g., short-term visual memory), should remain relatively intact. This hypothesis was tested by including two simple control tasks: short-term visual memory and a sustained visual attention task.

Encoding Deficits in Schizophrenia

Encoding involves the ability to attend to and select a stimulus for entry into WM by way of an internal representation. Several studies have highlighted encoding dysfunction as a possible source of working memory impairment in schizophrenia. Impaired encoding in schizophrenia may be the result of several possible sources, including inefficient allocation of attention between relevant and irrelevant information (Adler et al., 1998; Braver, Barch, & Cohen, 1999; Cohen, Braver, & Brown, 2002). Such allocation inefficiency may lead to a disruption or loss of spatial representation during the encoding phase (Glahn et al., 2003; Tek et al., 2002). Increasing the duration of the encoding period (Hartman, Steketee, Silva, Lanning, & McCann, 2002); or the attentional saliency of the encoded stimuli (Park, Swisher, & Knurek, 2001), improves visuospatial working memory among schizophrenics. The current study sought to determine if encoding enhancement might similarly counteract deficits in schizotypic SWM performance observed during the noisy-stress condition. We hypothesized that prolonging the encoding period would lead to significant improvement in schizotypic SWM as compared to the controls.

Method

Subjects

The Institutional Review Board at SUNY—Binghamton approved this study, and informed consent was obtained from all subjects. We assembled a sample of schizotypic subjects from a pool of 700 SUNY—Binghamton undergraduate students using the psychometric high-risk approach (Lenzenweger, 1994). The current study derived a sample of schizotypic subjects (at least 1.5 *SD*s above the mean) defined on the basis of scores on the Perceptual Aberration Scale (PER; Chapman, Chapman, & Raulin, 1978) or the Magical Ideation Scale (MAG; Eckblad & Chapman, 1983), or both scales. Use of a slightly lower selection cutoff for the schizotype group renders the group less of an "extreme group" and, if anything, will make obtained results more conservative. The Jackson Infrequency Scale (Jackson, 1984) was included among PER–MAG items in order to exclude random responders from participation. Investigators randomly selected control subjects from those who scored within .5 standard deviations from the PER–MAG means. Using the above criteria, we recruited 29 schizotypic subjects (69% women) and 45 controls (69% women). The undergraduate population at SUNY—Binghamton is highly diverse in terms of race, ethnicity, and socioeconomic status. Experimenters were blind to subjects' group membership. Subjects were compensated with course credit in their psychology course. All participants denied a prior history of psychotic illness, denied use of psychiatric medication at the time of the study, and stated they had not ingested psychoactive agents (e.g., nicotine or caffeine) within 24 hr of their participation. Table 1 depicts the sample's racial composition.

Measures

Schizotypic features assessment. There are many viable self-report psychometric and interview-based devices for the assessment of schizotypic features (see Lenzenweger, 2010). We used two of the most well established and well validated psychometric measures to tap schizotypic features in our screening protocol. The Perceptual Aberration Scale (PER; Chapman et al., 1978) is a self-report measure of body image and perceptual distortions. The Magical Ideation Scale (MAG; Eckblad & Chapman, 1983) is self-report questionnaire that measures beliefs in forms of causation that, by conventional standards of the dominant culture, are regarded as invalid and magical in nature. Both of these psychometric measures have been used extensively in laboratory research on schizotypic psychopathology (Chapman & Chapman, 1985; Chapman, Chapman, & Kwapil, 1995; Lenzenweger, 1994, 2010).

Numerous studies show that high scorers on the PER–MAG scales generally show many deficits similar to those seen in clinical schizophrenia (Chapman, Chapman, & Kwapil, 1995; Chapman, Chapman, Kwapil, Eckblad, & Zinser, 1994; Lenzenweger, 2010). Long-term follow-up studies of high PER–MAG scorers support the validity of these scales as measures of schizotypy (Chapman et al., 1994; Chapman et al., 1995) as well as results from a 17-year follow up of high PER scorers (Lenzen-

Table 1
Racial Composition of Study Subject Groups

	Racial group				
Subjects	Caucasian	Asian-American	African-American	Latino/a	Biracial
Controls	37 (82.2%)	2 (4.4%)	3 (6.7%)	1 (2.2%)	2 (4.4%)
Schizotypic	11 (37.9%)	11 (37.9%)	0 (0%)	3 (10.3%)	4 (13.8%)

weger, 2010). Moreover, in adult psychiatric inpatients with no prior history of psychosis, elevated PER scores are associated with elevated, clinically significant levels of schizotypal and paranoid personality disorder (PD) features as assessed by experienced doctoral clinicians using an established structured interview for Axis II psychopathology (Lenzenweger & Loranger, 1989b). Finally, it is important to note that Lenzenweger and Loranger (1989a) reported that deviance on the PER predicted a higher morbid risk for treated schizophrenia in biological first-degree family members, whereas PER elevations were *not* associated with a higher morbid risk for either bipolar illness or unipolar depression.

Spatial working memory task. Subjects were seated in front of a Macintosh computer approximately 24 in. away from the screen. On each trial of the SWM task, a small dot, approximately the size of a pencil eraser head, appeared on the screen for 500 ms. Subjects were asked to remember the location of the dot, because they were later directed to recall its location. On normal trials, the psychological refractory period, or the time between the offset of the target stimulus and onset of interference task, was 500 ms of a blank screen. On encoding enhanced trials, the psychological refractory period was increased to 1, 500 ms. The psychological refractory period was followed by the alternating squares interference task, which lasted approximately 10,000 ms. Following the interference task, the screen becomes blank and an auditory cue prompts subjects to recall the location of the dot by moving the mouse cursor and clicking where they believe the dot had appeared earlier. The dependent variable for the dot task is the distance between the clicked location and the actual location of the dot. The mouse cursor begins in the same location to ensure that the starting location is the same for all subjects on all trials. During the interference, or alternating-squares task, a series of squares appeared in the middle of the screen at the rate of 1 per 750 ms. Specifically, the onset of one square will last for 500 ms and then the offset will last for 250 ms, followed by the onset of another square. There are three sizes of squares, and subjects were instructed to count the number of times the square changes size across the presentation of 10 squares. Thus, the number of square changes could range from 0 to 9 times. To ensure consistent difficulty levels, the average number of square changes at each wave is 4.5. After subjects recalled the location of the dot in the dot recall task, subjects chose a number between 0 and 9 to indicate the number of times the square changed sizes. The difference between the actual number of changes and the number chosen by the subject was recorded for each trial. The absolute value was added across the trials to form an average score for each wave. The two dependent variables in the SWM task are (a) the distance between the location that the subject clicked with the mouse and the actual location of the dot measured in pixels; and (b) accuracy on the alternating squares interference task.

The task described above is similar to that used by Smith, Park, and Cornblatt (2006) in their study on SWM among adolescents at risk for schizophrenia. The primary differences in this protocol are that the squares in the intervening task cycled faster and a dependent variable was recorded for the intervening task. In addition to performing the SWM task at each wave, its component tasks, dot recall and alternating squares, were performed in isolation. These component tasks were used to determine if noise-induced stress affected simple and complex cognitive tasks equally.

Measures of stress response. Heart rate (beats per minute, BPM) was collected by an oximeter (CMS-50E Pulse Oximeter, Southeastern Medical Supply, Inc., Columbia, SC) attached to the ring finger of the subject's nondominant hand. The nondominant hand was used in order to ensure that subjects had the greatest degree of dexterity when controlling the mouse during the SWM task. The oximeter recorded BPM data every 5000 ms throughout the duration of the experiment. BPM was then uploaded to a computer and an average was taken for each of the four waves. Thus, fluctuation in the average BPM at each wave was considered indicative of change in stress response. Due to a brief equipment failure with the oximeter, BPM was not recorded for eight subjects.

Each subject also completed a brief self-report measure of perceived stress. It was important to include a subjective measure of perceived stress to ensure that the white noise was perceived as a stressor to both controls and schizotypic subjects. This "Noisy Stressor" questionnaire was administered immediately following the noisy stressor. The questionnaire consisted of five questions rated on a Likert scale from 0 to 10. Subjects were asked to rate their perceptions of stress during the white noise and the degree to which the noise negatively impacted their performance. We were interested in assessing not only their subjective experience of stress but also their perception as to whether it affected their performance.

Procedure. A noise stressor was chosen for two methodological reasons: first, the current investigation sought to understand how the concurrent presentation of a stressor during a working memory task affects performance, which is not possible with other popular stress paradigms (e.g., Trier Social Stress Test; Kirschbaum, Pirke, & Hellhammer, 1993); second, although pharmacological agents may induce physiological stress, such nonecologically valid stress inductions may not result in subjective stress (Wachtel, Charnot, & De Wit, 2001), which is more typical of natural, ecologically valid stressors such as noise (Smyth et al., 1998). Noise stress can significantly increase cortisol levels (Miki et al., 1998) and, more relevant to the current study, it can impair working memory by overexciting catecholamine activity (Arnsten & Goldman-Rakic, 1998). Based on previous findings that 85 decibels (dBA) can significantly increase heart rate and skin conductance (Cloete, 1979; Frankenhaeuser & Lundberg, 1977), 85dBA of white noise was presented during a SWM task as well as its component tasks, dot recall and alternating Squares. The frequency of the white noise was modulated every 15,000 ms to reduce habituation to the stressor.

Subjects performed a SWM task and its component conditions across four waves. There were a total of 16 trials of the SWM task at each wave, among which eight were normal trials and eight were encoding enhanced trials with psychological refractory periods increased by 1,000 ms. For the current study, the psychological refractory period refers to the time interval between the offset of the target stimulus (a small dot) and the onset of an interference task (alternating squares task). Baseline performance on the SWM task, the dot recall, and the alternating squares tasks was assessed at wave 1. In wave 2, subjects performed the same tasks in the presence of 85 dBA of white noise. Specifically, each participant was continuously exposed to 85 dBA of white noise for the duration of time they required to complete the three tasks consecutively, which was approximately 10 min on average. The white noise ceased upon completion of all tasks in wave 2 and was not emitted again. Following wave 2, subjects completed a questionnaire of perceived stress. After finishing the questionnaire of perceived stress, participants completed waves 3 and 4.

The task was designed to allow for data collection across four waves, however it is essential to note that waves 3 and 4 were included primarily to rule out the possibility of fatigue effects in the schizotypic group after the wave 2 stressor condition. The critical waves for this study are wave 1 (baseline) and wave 2 (noise/stress condition). It is important to note that there were no significant differences between controls and schizotypic subjects in SWM performance at waves 1, 3, and 4; this strongly suggests that the significant decrease in SWM at wave 2 was due to the effect of the noise manipulation rather than fatigue. If a fatigue effect better accounted for the significant decline in schizotypic SWM performance at wave 2, then the decline would have been present through waves 3 and 4 as well. In order to reduce the possibility of an order effect, there were four different orders of task presentation at each wave and subjects were randomly assigned to one of these orders. Subjects were never assigned to the same task order twice, thus no subject repeated the SWM, dot recall, or alternating squares in the same order as a previous wave. The order of the task presentation at wave 2 did not have a significant impact on the outcome variable of the dot recall, $F = .157$, $p = .925$, or the alternating squares portions of the SWM task, $F = 1.628$, $p = .191$. Our sample contained variation in race across five groups; however there were no significant interactions between group status and race for either the selection variables (PER or MAG) or between group and race on the critical wave 1 to wave 2 performance change on the SWM task (dot condition).[1]

Statistical Analysis

The differences between the groups were assessed using the *t* test, analysis of variance (ANOVA), and repeated measures ANOVA as appropriate. One-tailed statistical significance testing was done when a priori, theory-driven predictions guided the analysis in question. The theoretical basis for our one-tailed testing approach is found in our explicit prediction that stress should specifically erode SWM performance in the schizotypes. This prediction is consistent with a corpus of empirical evidence linking SMW to schizotypy (see Lenzenweger, 2010) as well as the extant literature on the impact of stress on neurocognitive performance. Furthermore, it is well known in data analysis that one-tailed significance testing adds increased power and precision to statistical analyses when used to assess a priori hypotheses. Cohen's *d* was used to estimate effect size from the group contrasts (Cohen, 1988). In the repeated measures ANOVA analyses for our SWM tasks and heart rate, we were specifically interested in testing a within-subjects quadratic contrast for the group by wave interaction as it would test the expected patterning of performance data across the waves with the noise-stressor at wave 2.

Results

Stress Response

BPM was used as an objective measure to estimate the stress level at each wave of data collection (see Table 2). Admittedly, heart rate is an imperfect measure of stress and not necessarily related to neurocognitive functioning (Park, Gibson, & McMichael, 2006), buy its extensive use in prior research argued for its inclusion. The two groups did not differ in baseline heart rate, $t(64) = 1.21$, *ns*, at wave 1. A Group (2) by Wave (4) repeated measures ANOVA with BPM (assessed by wave) as a within-subjects (repeating) variable across waves 1 through 4 revealed a significant group by wave interaction (within-subjects contrast—quadratic), $F(1, 60) = 4.03$, $p = .049$, two-tailed for the interaction of group by wave. Follow-up focused independent *t* tests comparing change in BPM between the controls and schizotypic subjects across the four waves revealed only a single significant change among the wave comparisons (i.e., wave 1 to 2). As hypothesized a priori, schizotypic subjects exhibited a significantly greater increase in BPM than controls during the noisy stress condition, $t(64) = 1.89$, $p = .032$, one-tailed, $d = .47$, indicating that the loud noise had a greater impact on heart rate in schizotypic subjects than controls. This pattern only emerged between waves 1 and 2, suggesting the increase in BPM was the result of the noisy stressor and not a fatigue effect. On a subjective measure of stress, schizotypic subjects rated the loud noise (wave 2) as significantly more stressful, $t(72) = -2.170$, $p = .017$, one-tailed, $d = .52$. Moreover, schizotypic subjects accurately perceived that the noise had a greater impact on their cognitive performance, $t(72) = -1.83$, $p = .036$, $d = .426$.

Table 2
Average BPM (Heart Rate) for Schizotypic and Control Subjects at Each Wave

	Schizotypic subjects		Controls	
Heart rate	*M*	*SD*	*M*	*SD*
Wave1	76.56	9.27	79.85	11.85
Wave2	79.10	9.33	81.05	12.01
Wave3	77.73	10.14	79.27	11.21
Wave4	76.48	10.13	78.84	11.70

[1] Our sample was richly diverse in terms of racial makeup. We examined the relations between this racial richness and both our selection variables (PER, MAG) as well as our critical spatial working memory dependent variable to ensure there were no systematic relations of race with these variables that should be taken into account. We conducted a group (schizotype vs. control) by racial group (5 levels) ANOVA for both the total Perceptual Aberration Scale (PER) and Magical Ideation Scale (MIS) scores. In neither case was there a statistically significant interaction between Group and Race (PER $F = .141$, $p = .935$; MIS $F = .583$, $p = .628$). Clearly, the most important variable in the entire study was the difference between baseline and the stress condition on the SWM task. In a two-way ANOVA, Group (2 levels) by Race (5), there was neither a significant group by race interaction ($p = .14$) nor a significant main effect for race ($p = .512$) on the SWM task. Furthermore, collapsing the racial grouping to just two levels (Caucasian vs. Non-Caucasian) the pattern of results was the same in that there were no significant group by race interactions for PER ($p < .96$), MAG ($p < .26$), or working memory ($p < .21$). The absence of significant interactions between group and race for the PER, MIS, and spatial working memory diminishes any salience of the differences in racial composition across our two subject groups (schizotypic vs. control).

Table 3
Error Performance on the Dot Recall SWM Task Across Waves

	Schizotypic subjects		Controls	
Dual dot task	*M*	*SD*	*M*	*SD*
Wave1	43.59	19.98	47.49	18.55
Wave2	50.80	35.63	39.49	13.98
Wave3	43.37	33.48	39.56	12.67
Wave4	43.22	32.74	40.99	18.11

Spatial Working Memory Performance

In order to examine SWM, two parallel repeated measures ANOVAs were conducted: one for the dot recall task and one for alternating squares task. The factorial design for these analyses was Group (2 levels) × Wave (4 levels) × Enhancement (2 levels), with group status as a between-subjects factor and both wave and enhancement as within-subjects factors. Based on prior research that suggests schizophrenics display encoding deficits (Glahn et al., 2003; Hartman et al., 2002; Park et al., 2001; Tek et al., 2002), it was hypothesized that prolonging the encoding period of the SWM task would benefit schizotypic subjects more than controls. Evaluation of the enhancement effect was a particular focus in this ANOVA as an absence of a significant effect for enhancement would allow us to discard the enhancement factor going forward and thereby increase power in subsequent analyses.

The Group (2) × Wave (4) × Enhancement (2) repeated measures ANOVA for the alternating squares index did not reveal a significant interaction of the enhancement factor with either wave or group or group by wave, nor was it a significant main effect, and it was thus left aside. Next, we examined alternating squares performance with a Group (2) × Wave (4) repeated measures ANOVA for the alternating squares and found no evidence of significance effects for group, wave, or the group by wave interaction (full results available upon request). We did not pursue the alternating squares index further.

The initial repeated measures ANOVA using the dot recall trials, the central SWM performance indexes in this study, revealed no significant main effect for enhancement nor any significant two-way or three-way interactions involving enhancement. However, we did find a significant group by wave interaction (tested as a hypothesized quadratic within-subjects contrast), $F(1, 71) = 3.94$, $p = .05$. We pursued this issue further with a Group (2) × Wave (4) repeated measures ANOVA, omitting the enhancement factor, and this ANOVA revealed a significant Group × Wave interaction (tested as a within-subjects contrast—quadratic), $F(1, 71) = 4.14$, $p = .046$. Inspection of the group means suggested that the change from wave 1 (baseline) to wave 2 (noise stressor) accounted for the interaction effect (see Figure 1). In a reduced Group by Wave (2-levels, W1 and W2) repeated measures ANOVA, the Group × Wave interaction was significant, $F(1, 72) = 7.12$, $p < .009$.

To better understand these Group × Wave interactions for the SWM dot recall data, we followed up with *t* tests on change indexes from each of the dot recall trials. Thus, we examined three change scores (W1–W2; W2–W3; W3–W4) calculated for each individual and tested across the two groups. Focused, independent *t* tests revealed, as hypothesized, schizotypic SWM performance worsened significantly during the noisy stress condition as compared to controls, $t(72) = 2.67$, $p = .005$, one-tailed, $d = .61$. The group differences for the W2–W3 and W3–W4 were not significant, suggesting the absence of a fatigue effect. Finally, tapping into individual differences across the schizotypic subjects, we found that dot recall performance at wave 2 (the loud noisy condition) was significantly correlated with the MAG scale in the expected direction ($r = .30$, $p = .011$, two-tailed) but not for the PER scale ($r = .05$, $p = .65$, two-tailed).

Sensitivity Analyses

Was the W1–W2 performance change in dot recall performance due to the impact of exceptionally deviant performance by one or two schizotypic subjects? Box-plot analysis of the dot recall data

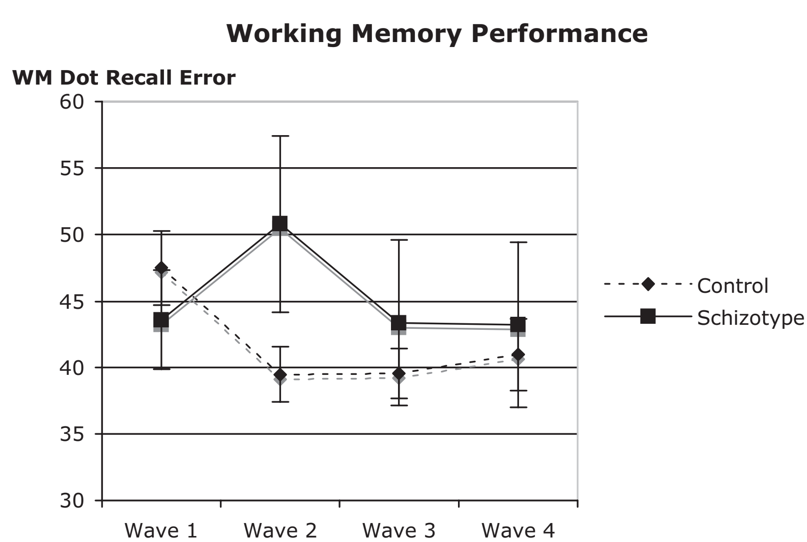

Figure 1. Mean performance on SWM task at four waves for schizotypic and control subjects. Bars represent standard error.

revealed two individuals with especially poor performance within the schizotypic group, as one would expect. However, to be conservative, we removed these outliers (two schizotypic subjects) from the analysis and found the group difference remained significant, $t(70) = 1.901$, $p = .03$, one-tailed, $d = .48$. However, since heterogeneity in performance is common laboratory data in schizotypy research (Lenzenweger, 2010) and deviant subgroups of subjects are expected, exclusion of these two subjects would be a methodological error (especially as the statistical analysis remained significant even in their absence). Also, in this context we note that the difference in SWM dot recall performance from wave 1 to wave 2 remained statistically significant ($p < .002$) even after taking the both wave1 baseline heart rate and the change in heart rate from wave 1 to wave 2 into account as covariates. Finally, the change in the dot recall portion of SWM, $t(71) = -.576$, $p = .57$ and BPM, $t(64) = -.484$, $p = .630$, between wave 1 and 2 was not better accounted for by sex differences.

This study also sought to determine if a loud-noisy stressor would differentially impact schizotypal performance on a simple versus complex cognitive task, like SWM. This distinction is important for two reasons: first, simple tasks serve as a control task to ensure that SWM was impacted more so than other cognitive tasks; second, we wanted to establish the level at which schizotypal cognitive performance is buffered from a noisy-stressor, which may be important for future analyses comparing schizotypic subjects and schizophrenics. This analysis was done by contrasting how schizotypic subjects compared to controls as they performed the dot recall and alternating-squares tasks concurrently (i.e., the SWM task) versus completing each task in isolation. When the dot recall and alternating-squares tasks (i.e., the simple tasks) were performed in isolation, as opposed to concurrently in the SWM task, there were no significant group by wave interaction findings for either the dot recall, $F(3, 69) = .957$, $p = .42$, or the alternating squares, $F(3, 69) = .224$, $p = .85$. Thus, the noisy stressor did not have a significant effect on schizotypic performance during simple cognitive tasks.

Discussion

The present study examined the effects of a loud-noise stressor on SWM performance in a sample of schizotypic subjects. The schizotypic subjects experienced a significant increase in BPM and subjective ratings of stress and a significant decrease in SWM performance when the loud-noise stressor was presented. Specifically, schizotypic performance on the dot recall portion of the SWM task worsened significantly from the quiet, baseline condition to the loud-noise condition in comparison with controls, whose performance improved with the loud noise. These results are consistent with the notion that schizotypic subjects would exhibit an exaggerated stress response to a common environmental stressor, like loud noise. Moreover, the results were consistent with the conjecture that the loud noise would lead to diminished SWM performance. This is a particularly exciting finding because prior research had shown (a) an exaggerated stress response in schizophrenia (Lindström, 1996; Williams et al., 2004) and schizotypy (Brunelin et al., 2007; Brunelin et al., 2008; Castro et al., 2009; Myin-Germeys, Delespaul, & van Os, 2005) and (b) schizophrenia patients exhibited a sensitized dopaminergic response to stress (Mizrahi et al., 2011). Yet, based on this research corpus, it was not clear whether or how stress would affect performance on complex cognitive tasks such as SWM. The absence of a correlation between BPM and performance on the SWM task makes it difficult to draw inferences regarding the relationship among schizotypy, arousal, and SWM. Thus, although it does appear that the loud noise eroded SWM among the schizotypic subjects, the mechanism through which this occurred is unclear. One possibility is that processing the loud noise further taxed the central executive component of working memory, thus leading to a greater decrease in available attentional resources for the SWM task among schizotypic subjects. The noisy stressor did not have a significant impact on simple cognitive tasks (i.e., the dot recall and alternating-squares tasks when administered separately), which suggests that schizotypic subjects may have a greater capacity to buffer some aspects of cognitive functioning from the effects of stress. Finally, although we considered the possibility that a temporal enhancement might allow for more effective encoding (possibly offsetting the impact of the noisy stressor in the SWM condition), we did not find evidence for a performance benefit associated with this enhancement. Given the prior literature that has raised the possibility of encoding deficits in schizophrenia, we must consider the possibility that the encoding enhancement effect in our sample may have been modest enough to elude detection given our statistical power.

The present study indicates that schizotypic subjects exhibit reduced SWM performance when faced with loud noise. Nevertheless, as noted, the source of these deficits and the precise process underpinning them remain unknown. A potential developmental implication of our findings concerns the role of stress in the conversion of those individuals who possess an unexpressed liability for schizophrenia to actual clinical illness. Consider that life in many urban areas is associated with ongoing noise on a daily basis. We found that working memory in schizotypic individuals interacts with stress in such a manner that working memory impairments clearly result. Such reductions in working memory functioning may lay the ground work for the emergence of psychosis. As such our results may provide a useful link in explaining the chain of events from risk status for psychosis to clinical illness. We offer this speculation in the context of discovery and for its heuristic value.

Results from the present study suggest a more practical concern. We suggest that researchers may want to take into account the potential for stress-response artifact caused by loud noises in research. This is something to be considered when stress is the direct object of scientific attention in the research, but it is just as important when stress may not be thought of as of direct interest yet noise levels are high in a research setting. Consider for example the loud noises emitted during the imaging process by *f*MRI scanners, which could then plausibly affect both imaging data as well as some cognitive tasks administered while gathering imaging data. As a result, researchers may choose to conduct a control condition outside of the *f*MRI machine to determine if potential stressors (e.g., loud noise and enclosed space) have introduced artifact into the results. Additionally, if a cognitive task is administered while subjects are in the *f*MRI scanner, it would be important, in light of our results, to collect imaging data in the absence of this cognitive task. This will allow researchers to isolate the effects of the loud noise of the *f*MRI scanner on imaging data to highlight those areas of the brain that are responding to loud noise versus the cognitive task.

There are several caveats to the present study. First, our schizotypic subjects were selected on the basis of deviance on two psychometric measures—PER and MAG. Although both of these measures as associated with outstanding construct validity, it is possible that our results are primarily related to a variant of schizotypal personality defined by positive-like features (perceptual illusions, magical thinking). Second, it is possible that some of those persons designated as schizotypic may not be schizotypic just as some of the controls may not be entirely without schizotypic features. No measure of schizotypic features, whether assessed psychometrically or via an interview, is perfect and all are fallible. Therefore, false positives and false negatives will result in any sort of classification or selection effort. Third, we used a noise condition to create stress in our subjects. It may be that our noise stressor possessed ecological validity; it is clearly the case that humans routinely encounter higher levels of noise (e.g., airport tarmac noise, automobile and train noises) as well as other types of environmental stressors. Thus, it could be that future research might want to probe other stress inductions in terms of greater noise intensity or different types of stressors. Fourth, perhaps most notably, the only objective measure of stress response, BPM, did not correlate with performance on the SWM. Although it appears that the loud noise did erode schizotypic SWM, it is uncertain if this was mediated by the stress response or some other variable. Since BPM is just one aspect of a stress response, it would have been informative to have included additional objective measures of stress response (e.g., galvanic skin response or measures of cortisol release) to better understand those aspects of the loud noise that led to impoverished SWM performance. Heart rate is a problematic measure in and of itself, thus it cannot be relied upon as a physical index that is unambiguous in meaning (Kagan, 1994; see also Park, Gibson, & McMichael, 2006). Using BPM as the sole means for inferring stress response constrains the degree to which definitive conclusions can be made regarding the interactions among loud noise, stress, and SWM. Fifth, one must always consider the possibility of psychometric artifact in an experimental study where performance change is observed on an index or process after a manipulation (e.g., noise condition relative to baseline). However, proposed psychometric matching remedies to this challenge have not proven especially fruitful in psychopathology research and can often themselves lead to interpretive ambiguities (e.g., matching two cognitive tasks on discriminating power in a control group may alter the underlying cognitive processes under investigation). We are mindful of the pros and cons surrounding matching laboratory tasks on discriminating power. Finally, one must consider if one or two outliers drive the findings of a study. In this study, the primary finding for the SWM performance measure of interest remained statistically significant in terms of schiztotypic subjects versus controls even when the two most deviant schizotypic performers were removed from the analysis.

In sum, our results provide preliminary evidence linking a personality disorder variant—schizotypic personality—to a reduction of a critical neurocognitive function (SWM) in the face of a common stressor: noise. In exploring this issue, we offer these results for their potential utility, perhaps identifying an endophenotype (Gottesman & Gould, 2003; Lenzenweger, 1999), in understanding the impact of stressors on those who may be at increased risk for schizophrenia or schizophrenia-related psychotic illness (e.g., delusional disorder, schizophreniform illness).

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