Pupillary Dilation to Simple Versus Complex Tasks and its Relationship to Thought Disturbance in Schizophrenia Patients

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Abstract

Task-evoked pupil dilation is a measure of attentional allocation. Schizophrenia patients have pupil dilation deficits during high cognitive load tasks, which have been attributed to attentional resource deficits. Moreover, this attentional impairment is thought to be linked to cognitive fragmentation and thought disturbance. Previous attempts to associate attentional deficits to thought disturbance have typically measured these domains at distinct times, incorrectly assuming that both are static variables. In this study we compared the pupil dilation of 24 schizophrenia patients to 15 non-patients during complex (Rorschach blots) versus simple visual (line drawings) processing tasks while simultaneously assessing their verbal responses for thought disturbance. Schizophrenia patients’ dilation to the simple stimuli was similar to the non-patients; however they demonstrated significantly less dilation to the complex stimuli. Reduced dilation was also significantly correlated with reduced response complexity and more severe thought disorder. The results suggest that, in the face of complex problem-solving situations, greater attentional impairment and cognitive overload in schizophrenia is associated with higher levels of disturbed and impoverished thinking. These findings support the “resource limitations hypothesis” of schizophrenia and underscore the utility of a simultaneous paradigm when studying the relationship between attentional deficits and thought disturbance.
Introduction

Pupillary response or the change in an individual’s pupil size during performance of a cognitive task is a measure of the degree of attentional resources or “cognitive effort” allocated to the task (Beatty, 1982). For example, when digits are auditorially presented to a subject for their retention and recall, the subject's pupil size increases successively as each digit is read aloud and decreases as he or she repeats back each digit (Granholm, Asarnow & Marder, 1996a, Peavler, 1974). The pupil does not dilate further after the number of digits exceeds the subject’s capacity to attend to and retain digits. Hyona and colleagues (1995) examined the pupillary response of normal subjects during language tasks of varying difficulty and reported that high “cognitive load” or more complex tasks, such as translating difficult words or repeating words in a non-native language, elicited more dilation than “low cognitive load” tasks, such as translating easy words or repeating native-language words. These findings are among the many that illustrate the use of pupillary response as a measure of attentional allocation and task processing load.

Several authors have reported that individuals with schizophrenia have reduced pupillary responses (Granholm, Morris, Asarnow, Chock & Jeste, 2000, Granholm, Morris, Sarkin & Asarnow, 1997, Steinhauer & Hakerem, 1992, Steinhauer & Zubin, 1982). This finding is consistent with the "resource limitations hypothesis" which suggests that schizophrenia patients have a general diminishment in their “pool” of available attentional resources when processing higher cognitive-load tasks (Granholm et al., 1996a, Granholm, Asarnow, Sarkin & Dykes, 1996b, Granholm et al., 1997, Nuechterlein & Dawson, 1984, Nuechterlein, Edell, Norris & Dawson, 1986, Walker &
Granholm and colleagues (2000) recorded pupillary responses during a task that required attention to a large array of information (high processing load) versus a low processing load task. Schizophrenia patients had normal pupil dilation in the low load condition but significantly reduced dilation on the high processing load condition compared to non-patients. Granholm et al.’s finding is consistent with several studies showing that schizophrenia patients do not have performance deficits during simple, low-load tasks (Belloch, Banos & Perpina, 1991, Vinogradov, Ober & Shena, 1992) but do evidence attentional impairment when faced with a complex or highly affectively charged task (Perry & Braff, 1995, Perry, Geyer & Braff, 1999). Furthermore, several authors have suggested that the attentional impairment of schizophrenia may be associated with cognitive fragmentation and frank thought disturbance, particularly under complex processing conditions (Braff, 1985, Braff, 1993, Perry & Braff, 1994, Perry et al., 1999, Saccuzzo & Braff, 1986, Walker & Harvey, 1986). For example, Solomon and colleagues reported a relationship among schizophrenia patients between eye tracking dysfunction and thought disorder measured with the Rorschach Test (Solomon, Holzman, Levin & Gale, 1987). Similarly, Perry and his colleagues have repeatedly demonstrated a relationship between impaired sensorimotor gating, a measure of attention and information processing, and Rorschach measures of thought disturbance (Perry & Braff, 1994, Perry et al., 1999).

These studies demonstrate the utility of studying attentional functioning and thought disturbance under experimentally controlled conditions versus measuring thought disturbance with observer-rated symptom scales. Perry has suggested that symptom scales do not fully capture thought disturbance as these measures are subject to rater bias.
and rely on the patient being forthcoming with information (Perry & Braff, 1994). Thus, rating scales have been criticized for a lack of sensitivity to subtler manifestations of thought disturbance. Additionally, studies relating attentional allocation to thought disturbance have measured these two domains of impairment at different times, with different tasks. Inherent to this design is the supposition that attentional resources are consistent across tasks despite differential task difficulty. This assumption, referred to as “cold cognition”, has been criticized (Gjerde, 1983), because attention and thought disturbance are not static variables and do vary over time as a result of differential stimulus and task load (Perry et al., 1999).

The aim of the present study was to examine pupillary responses to simple and complex tasks while simultaneously recording behavioral samples of thought disturbance. Subjects were exposed to and asked to verbally identify two sets of stimuli. The simple stimuli consisted of line drawings of readily identifiable objects, while Rorschach inkblots were used as the complex stimuli. The Rorschach has been conceptualized as a high cognitive load and abstract visual problem-solving task (Acklin & Wu-Holt, 1996, Exner, 1993, Perry & Braff, 1994, Perry, Potterat, Auslander & Kaplan, 1996, Perry & Potterat, 1997, Viglione, 1999) and elicits verbal samples of disturbed thinking in schizophrenia patients that can be easily and reliably scored (Perry, Minassian, Cadenhead, Sprock & Braff, 2003). The development of this novel paradigm with the Rorschach allows us to address the criticism of "cold cognition" by measuring attentional allocation and thought disturbance simultaneously. We hypothesized that the pupillary responses of schizophrenia patients would be similar to non-patient comparison subjects on the low-load task, but that schizophrenia patients would show significantly reduced
dilation when compared to non-patients on the high-load task. Additionally, based on previous literature showing a link between impaired attention and increased thought disturbance (Perry & Braff, 1994, Perry et al., 1999, Solomon et al., 1987), we hypothesized that decreased dilation would be related to higher levels of disturbed thinking among the schizophrenia patients.

Method

Subjects

Twenty-six patients with DSM-IV diagnosed schizophrenia (20 males, 6 females) were examined. Diagnoses were determined using the Structural Clinical Interview for DSM-IV (SCID-IV) (First, Spitzer, Gibbon & Williams, 1994). We have previously established a 98 percent agreement for determining Axis I diagnoses using the SCID (Perry et al., 2001). The schizophrenia patients were directly recruited from the psychiatric services of the UCSD Medical Center, as well as from other local inpatient psychiatric facilities and outpatient clinics. Two schizophrenia patients had excessive eyeblinks during the data collection trials, prompting discarding of their psychophysiological data and resulting in a final sample of 24 (18 males, 6 females).

Fifteen (10 M, 5 F) nonpatient comparison subjects were recruited with the use of newspaper announcements and flyers advertising this study, and were screened for Axis I and II disorders using the SCID-IV. Potential subjects were excluded if they (a) met diagnostic criteria for substance or alcohol abuse or dependence within six months prior to participation in this study, (b) had experienced a major head injury or reported a history of neurologic dysfunction such as seizure disorder, (c) did not have at least 20/30 vision on a Snellen wall chart with use of corrective lenses, (d) had experienced a
significant eye injury or had an eye disease that impairs vision, pupillary function, or eye movement, or (e) had taken the Rorschach test within 6 months prior to participation in this study.

All subjects were between 18 to 55 years of age. Nonpatient comparison subjects and schizophrenia patients did not significantly differ in terms of age, $t(37) = 1.5, p = .14$. The nature of the population of the psychiatric services, with a sex ratio heavily favoring males, resulted in an uneven male-to-female ratio (Table 1); however the sex ratio did not significantly differ between groups, $\chi^2 = .66, p = .46$. Schizophrenia patients had on average completed fewer years of education than normal comparison subjects, $t(37) = 2.34, p = .03$. To obtain a general estimate of verbal intellectual functioning, the Wechsler Adult Intelligence Scale-Revised (WAIS-R) (Wechsler, 1981) Vocabulary subtest was administered to all subjects. Schizophrenia patients had significantly lower WAIS-R Vocabulary Scores than nonpatient comparison subjects, $t(37) = 3.98, p < .001$. See Table 1 for comprehensive demographic information.

For the purposes of analysis, antipsychotic medication dosages were converted into chlorpromazine equivalents and anticholinergic medication dosages were converted into benztropine equivalents (Sadock & Sadock, 2000). The majority of the schizophrenia patients were prescribed a single antipsychotic agent at the time of testing; however seven subjects were being treated with a combination of two antipsychotic
medications (e.g. risperidone and olanzapine), and 3 subjects were not taking any antipsychotic medications at the time of testing. Including the 7 subjects being treated with more than one agent, medications for the schizophrenia patients were as follows: 5 were receiving typical antipsychotic medications ($M_{CPZ\text{ equiv}} = 135.14$ mg, $SD = 338.05$), 6 were receiving olanzapine ($M_{dose} = 15.83$ mg, $SD = 8.0$), 3 were receiving clozapine ($M_{dose} = 203.33$ mg, $SD = 195.0$), 8 were receiving risperidone ($M_{dose} = 3.0$ mg, $SD = 1.5$), 1 was receiving quetiapine (dose = 600 mg), and 1 was receiving ziprasidone (dose = 160 mg). Additionally, seven of the schizophrenia patients were also being treated with an anticholinergic medication at the time of testing ($M_{benztropine\text{ equivalent}} = 2.57$ mg, $SD = 1.1$).

**Procedure**

This study was reviewed and approved by the Human Research Protections Program of the University of California, San Diego. Subjects were informed of the general nature and procedure of the experiment and consented, and demographic information was collected. The SCID-IV was then administered to establish diagnosis. Schizophrenia patients’ symptoms were evaluated with the Scale for the Assessment of Positive Symptoms (SAPS) (Andreasen, 1984b) and the Scale for the Assessment of Negative Symptoms (SANS) (Andreasen, 1984a). Schizophrenia patients had a mean SAPS score of 9.0 ($SD = 4.1$) and a mean SANS score of 9.2 ($SD = 5.8$). Mean age of onset of psychiatric illness was 21.2 years ($SD = 6.4$), and mean number of psychiatric hospitalizations was 7.5 ($SD = 7.6$).

Subjects were tested in a lighted room and were asked to place their chin in a chinrest and their forehead up against a forehead bar. Ambient light in the room was
measured at 160 lux. An elastic strap was placed around the back of their head to facilitate head stabilization. Subjects were asked to focus on a computer monitor 67 cm away from their head.

Pupillary activity and eye movement were recorded with the use of an infrared corneal-reflection-pupil-center pupillometer (Micromeasurements System 7000). An infrared light source was positioned below the subject’s left pupil and a video camera sensitive to infrared light recorded the size of the pupil and the position of the eye at a sampling rate of 60 Hz, with a resolution of .02 millimeters. Subjects were asked to look at the center of the computer monitor screen while the experimenter adjusted the recording equipment to obtain a centered, focused image of the subject’s left eye. An infrared image of the eye was presented on a TV monitor that was shielded from the subject’s view. Once an accurate image was obtained, the recording equipment was calibrated to so that an accurate estimate of the eye’s position on the screen could be maintained.

Stimuli from the Rorschach Inkblot Test were scanned into the computer to produce images on the screen with an average dimension of 14.2 by 14.9 cm (13.4 x 14.5 degrees of visual angle). The computer images of the Rorschach have been matched to the original stimuli as closely as possible with respect to color and shading elements. Subjects were presented with a modified version of the standard Comprehensive System directions for the administering the Rorschach (Exner, 1995). Each Rorschach image was presented right side up and remained on the computer screen for 30 seconds. During exposure to the Rorschach subjects were instructed not to talk or move. At the end of the
30-second exposure the image was removed from the screen and subjects were then asked to verbalize their response to the stimulus.

In between Rorschach stimuli, a blank white screen with a dark square in the center was presented to the subject. The purpose of this screen was to provide the subject with a fixation point that remained consistent across trials. The light emission of each screen was measured in lux with the use of a light meter and was adjusted so that it emitted the same brightness as the Rorschach stimulus following it. The aim of matching light emissions in this manner was to minimize the constricting or dilating reaction of the pupil to light changes.

Subjects were also administered a shortened, 10-picture computer version of the Boston Naming Test (BNT) (Kaplan, 1976). The BNT consists of simple black-and-white line drawings of objects that subjects are asked to identify by name. The ten pictures used in this study were selected for varying degrees of naming difficulty and scanned into the computer in the same manner as the Rorschach stimuli. Instructions for this test were presented to the subject in a similar fashion to that of the Rorschach instructions. The administration of the BNT matched the Rorschach administration as closely as possible: i.e. there was a light-matched fixation screen preceding each picture, subjects were asked not to talk or move while they looked at the picture and psychophysiological data was collected, and subjects responded to the picture after it had been automatically removed from the screen after a 30-second exposure. The BNT stimuli and fixation screens were matched to the Rorschach stimuli for luminance.

Fourteen of the 24 schizophrenia patients and all 15 of the nonpatient comparison subjects were administered the Rorschach test first, followed by the BNT. To examine
task order effects, the other ten schizophrenia patients were administered the BNT first, followed by the Rorschach.

Data Analysis

The pupil data was passed through a seven-point smoothing filter and artifacts such as large eye movements and blinks were removed (Granholm et al., 2000). Pupil size was sampled in units of area and subjected to a computer algorithm written by one of our co-authors (S.V.) to convert area to diameter. Baseline pupil size was defined as the diameter of the pupil before the onset of each visual stimulus. The average difference in pupil size from baseline over the first ten seconds of stimulus presentation was calculated.

Rorschach responses were scored according to the Comprehensive System (CS) (Exner, 1995). CS data is referenced to large samples of normal and patient populations, and is the most commonly accepted method of Rorschach scoring. Two CS indices of thought disturbance were extracted. The Form Quality Minus score (X-%) assesses perceptual inaccuracies in formulating responses to the Rorschach stimuli, e.g. accurate perception of the salient features of the blots. X-% is generated by calculating the proportion of responses in the record that do not appropriately use the contours of the blot. These low frequency responses violate the perceptual parameters of the stimulus and reflect problems in reality testing, or seeing things as others do. The Cognitive Special Scores index (WSUM6) is a summary score comprised of three different categories of unusual thinking: deviant and odd verbalizations, inappropriate combinations or unrealistic relationships between objects, and the use of strained, illogical reasoning to justify a response. Thus, the WSUM6 score assesses impaired reasoning and cognitive
slippage, autistic logic, and disorganized thought and language. Examination of the
distribution of the WSUM6 score in schizophrenia patients revealed that this score was
significantly positively skewed and leptokurtotic. Therefore, the WSUM6 score was
transformed using a square-root transformation (Tabachnick & Fidel, 1989), and this
transformed score was used in subsequent analyses. Additionally, the Rorschach
Response Complexity score (Viglione, 1999) was calculated for each subject. Response
complexity has been defined by Viglione (1999) as “the amount of productivity,
precision, differentiation, and integration involved in the aggregate of all responses”
(p.259) and is thought to be associated with problem-solving ability. High response
complexity is demonstrated when the subject takes full advantage of the complex aspects
of the blot, i.e. integrating discrete areas of the blot into one response, using various
elements of the abstract visual field such as color and shading, and identifying multiple
percepts.

To test the main hypothesis of this study, a Repeated-Measures ANOVA was
conducted with task (Rorschach versus BNT) as the repeated measure and subject group
(schizophrenia patient versus nonpatient comparison subject) as the between-subjects
measure. Post-hoc comparisons were examined with two-tailed independent samples t-
tests, and Cohen’s d magnitudes of effect were calculated. Pearson correlations were
computed between average Rorschach pupillary response and thought disturbance
variables, and between thought disturbance variables and pupillary responses on the ninth
and tenth blots of the Rorschach. These blots are thought to be the most abstract and
difficult for schizophrenia patients to generate a response (Wagner & Hoover, 1970),
therefore the most likely to elicit thought disturbance. All analyses were conducted with SPSS 10.0 software (SPSS, 1995). Significance levels were set at $p \leq .05$.

Results

Pupillary Response

Examples of raw waveforms of pupil data are displayed in Figure 1. Both schizophrenia patients and non-patient comparison subjects showed less pupil dilation to the BNT than to the Rorschach, [main effect of task, $F(1, 37) = 91.86$, $p < .001$, $d = 2.20$]. Additionally, there was a significant task-by-group interaction, $F(1, 37) = 13.35$, $p = .001$. Post-hoc t-tests indicated that that the schizophrenia patients had significantly smaller average dilation to the Rorschach task than the non-patient comparison subjects, $t(37) = 3.61$, $p = .001$, $d = 1.22$; however the schizophrenia patients’ dilation to the BNT task did not significantly differ from that of the non-patient comparison subjects, $t(37) = .76$, $p = .46$, $d = .26$. (Figure 2).

To address whether baseline pupil size for either the Rorschach or the BNT stimuli affected task-evoked pupillary response, the above analysis was repeated using average pupil size before onset of stimuli (baseline) as a covariate. This did not significantly impact the main results; there remained a significant main effect of task [Rorschach baseline: $F(1, 36) = 14.42$, $p = .001$; BNT baseline: $F(1, 36) = 4.17$, $p = .05$] and a significant task-by-group interaction [Rorschach baseline: $F(1, 36) = 16.88$, $p < .001$; BNT baseline $F(1, 36) = 13.02$, $p < .001$].

To assess whether the order that the two tasks were presented had a differential impact on the results, the fourteen schizophrenia patients who were presented the Rorschach first were compared to the 10 schizophrenia patients who were presented the
BNT first in a 2 (Order) x 2 (Task) ANOVA. There was a significant main effect of task, \( F(1, 22) = 18.3, p < .001, \text{d} = 1.26, \) indicating that both groups showed less dilation to the BNT than to the Rorschach. In contrast, neither the main effect of order (Rorschach first versus BNT first), \( F(1, 22) = .81, p = .38, \text{d} = .59, \) nor the task-by-order interaction, \( F(1, 22) = 1.86, p = .19, \) were significant.

**Pupillary Response and Medication Effects**

To determine whether pupillary response was related to dose of antipsychotic medication, doses were converted into chlorpromazine equivalents and were correlated with pupillary response. Chlorpromazine equivalents were not significantly correlated with pupillary response to the Rorschach, \( r = .12, p = .61, \) nor with pupillary response to the BNT, \( r = -.004, p = .99. \) To determine whether anticholinergic medications were related to pupillary response, a two-tailed independent samples t-test was conducted on pupillary response between schizophrenia patients on \( (n = 7) \) and off \( (n = 17) \) anticholinergic medications at the time of testing. Pupillary response to the Rorschach was not significantly different between these two groups, \( t(22) = 1.57, p = .13, \text{d} = .74; \) however pupillary response to the BNT was significantly smaller for the patients on anticholinergic medications, \( t(22) = 2.43, p = .02, \text{d} = 1.14. \) Subsequently, the hypotheses of the study were re-examined with a new database where the seven schizophrenia patients on anticholinergic medications were removed from the analysis. Removing these subjects did not significantly change the results so that there was still a main effect of task, a significant task by group interaction, and no task by order interaction.
Pupillary Response and Thought Disturbance

To assess the relationship between Rorschach-evoked pupillary response and thought disturbance indices from the Rorschach, Pearson correlation coefficients were generated for the schizophrenia sample and, due to the nature of the hypothesis, subjected to one-tailed significance tests. There was a trend towards a significant correlation between Rorschach-evoked pupillary dilation and the Form Quality Minus perceptual inaccuracy measure (X-%), $r = -.31$, $p = .06$. The correlation between X-% and pupillary response to Blot Nine was statistically significant, $r = -.37$, $p = .03$, as was the correlation between X-% and Blot Ten, $r = -.39$, $p = .03$. Rorschach-evoked pupillary dilation was also correlated with the square-root transformed WSUM6 bizarre thought processes score, $r = -.33$, $p = .05$. The correlation between WSUM6 and Blot Nine pupillary response was significant, $r = -.34$, $p = .05$, and there was a trend towards a significant correlation between WSUM6 and Blot Ten pupillary response, $r = -.31$, $p = .07$. The correlation between Rorschach-evoked pupillary dilation and the Rorschach Response Complexity score was significant, $r = .56$, $p = .005$, indicating that among schizophrenia patients, larger pupillary dilation was associated with more complex, integrated Rorschach responses.

Post-hoc correlations were also conducted between Rorschach pupillary response and symptom scores for the schizophrenia patients. There was no significant correlation between pupillary response and SAPS scores, $r = -.02$, $p = .92$, but the correlation between pupillary response and SANS scores did reach statistical significance, $r = -.43$, $p = .03$, such that less dilation was associated with higher SANS scores.
Discussion

The findings of the current study support our hypothesis that schizophrenia patients evidence reduced pupil dilation compared to non-patient comparison subjects during the processing of a complex visual problem-solving task. Schizophrenia patients showed abnormally reduced pupil dilation during the complex (Rorschach) but not the simple (BNT) visual processing task. This finding is consistent with previous reports of decreased task-evoked dilation in schizophrenia in response to complex or high cognitive load tasks (Granholm et al., 2000, Steinhauer & Zubin, 1982, Zahn, Frith & Steinhauer, 1991). The order in which the BNT and the Rorschach were presented did not significantly affect the findings and rule out the possibility that less dilation to the BNT in schizophrenia patients was indicative of habituation of the pupillary response. This finding also cannot be attributed to the schizophrenia patients having less dilation across all tasks, as both the patients and non-patients showed significantly more dilation to the processing of the complex Rorschach stimuli than to the BNT and the pupillary responses of the two groups did not significantly differ on the BNT. As a caution, detailed inspection of the means revealed that both groups’ average pupillary size after exposure to the BNT was below that of pupil size at baseline. The relative negative dilation to the BNT may due to a “floor effect” in processing simple stimuli, and consequently may have confounded the ability to detect group differences on the BNT.

Beatty (1982) and others (Hyona, 1995) have asserted that pupil dilation is a sensitive measure of “processing load”, or task difficulty. Rorschach stimuli are ambiguous and abstract, and the task requires a high degree of processing effort in order for the subject to generate a meaningful interpretation of the stimuli. The BNT line
drawings, in contrast, are simple, obvious and easily identifiable stimuli that can be processed virtually “automatically” and without great cognitive effort. Thus, the finding of normal allocation of attention during the BNT is consistent with Gjerde’s (1983) and Neuchterlein and Dawson’s (1984) assertions that schizophrenia patients do not show marked attentional deficits when engaging in low-cognitive load tasks. The present results therefore support the resource limitations hypothesis that, when schizophrenia patients are faced with a novel and complex task, their allocation of attentional resources is taxed, limiting their ability to optimally process salient information (Gjerde, 1983, Granholm et al., 2000, Nuechterlein et al., 1986).

A second hypothesis of this study was that decreased Rorschach-evoked dilation would be related to increased indices of thought disturbance among the schizophrenia patients. Our results indicated that, in general, there was an association between smaller pupillary response and higher levels of perceptual inaccuracy and bizarre thought processes, especially on blots thought to be most sensitive to eliciting thought disturbance. Restricted range of the severity of thought disturbance in this schizophrenia sample may have weakened the strength of these correlations, as the Rorschach responses of many of the schizophrenia patients were markedly more restricted and impoverished than were the protocols of the normal comparison subjects. In fact, a strong relationship was found between pupil dilation and Rorschach response complexity, suggesting that decreased attentional allocation was associated with simplistic, impoverished, and guarded Rorschach responses. Concurrently, as the pupil dilation of schizophrenia patients increased, their Rorschach responses became more complex, productive and organized. Finally, positive symptom severity ratings on the SAPS showed no
relationship to pupillary response, but greater negative symptom severity on the SANS was significantly associated with smaller pupillary response. This is consistent with the view that negative symptomatology is associated with cognitive and attentional impairment (Nuechterlein et al., 1986). Taken together, these findings suggest that attentional impairment and cognitive overload in patients with schizophrenia is associated with fragmented thinking and more severe thought disturbance (Braff, 1985, Braff, 1993, Perry & Braff, 1994, Saccuzzo & Braff, 1986, Walker & Harvey, 1986).

There are some limitations in the study that need to be considered when interpreting the results. As this was a naturalistic design, medications were not controlled for. Still, pupillary response did not appear to be significantly impacted by antipsychotic medications. Anticholinergic medications are known to increase the baseline size of the pupil (Julien, 1995); however in the current study, when the patients taking anticholinergics were removed from the analyses, the results were not significantly affected. Although the current pupil dilation findings are probably not explained by medication effects, future work with larger samples of schizophrenia patients are needed to determine the impact of medication status on our results. Another limitation of this study was the lack of counterbalancing of non-patient comparison subjects for order of tasks (Rorschach first versus BNT first and vice versa). We found that task order did not significantly impact our pattern of results, but future replication of these findings should include a more consistently counterbalanced design. Additionally, although Granholm et al. (2000) endorse the measure of average pupillary response as an acceptable measure of resource allocation, recent alternative methods of analysis have been used, with good results. For example, Verney (Verney, Granholm & Dionisio, 2001) used a principal
components analysis to characterize pupillary response and successfully identified several specific factors that were hypothetically associated with successive stages of resource allocation and information processing. Marshall (Marshall, 2000) has used mathematical functions termed “wavelets” to successively decompose pupillary responses so that artifacts that are not related to task-evoked dilation, such as light oscillation, are filtered out and a more “pure” index of processing load theoretically emerges. These interesting advances in the examination and understanding of pupillary dilation may prove valuable in the continued research to characterize attentional capacity and limitation.

In conclusion, a novel paradigm was developed to simultaneously assess pupil dilation and thought disturbance during both low and high cognitive-load conditions. Our results suggest that schizophrenia patients are characterized by a decreased ability to allocate attention and cognitive effort to challenging problem-solving situations, but do not evidence attentional problems when demands from the environment are limited and straightforward. This reduced attentional allocation was associated with more severe thought disturbance. This novel design offers a promising means of studying the hypothesis that attentional abnormalities are closely associated with thought disturbance in schizophrenia, as we can examine attention and verbal responses in a simultaneous manner. Future efforts can capitalize on this paradigm by relating trial-by-trial pupil dilation with trial-by-trial incidences of disturbed thought. This approach can then be applied to sophisticated techniques such as functional imaging, and can facilitate a significant forward advance in our understanding of the relationship between attention and thought disturbance.
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Table 1. Means and standard deviations for demographic information for nonpatient comparison subjects (n = 15) and schizophrenia patients (n = 24).

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<th>sex</th>
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Figure Legends

Figure 1. Raw waveforms for pupillary response (change in pupillary diameter) to Blot 1 of the Rorschach Inkblot Test for one normal comparison subject and one schizophrenia patient.

Figure 2. Mean pupillary response (change in pupil diameter) ± 1 S.E.M. recorded during performance of the Rorschach Inkblot Test and the Boston Naming Test (BNT) for schizophrenia patients and non-patient comparison subjects.
pupillary response (mm)

nonpatient comparison subject schizophrenia patient

time (0 - 10 seconds)
Pupillary response (mm)

Rorschach  BNT

-0.2  -0.1  0  0.1  0.2  0.3  0.4

-0.2  0  0.1  0.2  0.3  0.4

nonpatient comparison subjects schizophrenia patients