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Tapping in Time: Visual and Auditory Selective Attention in Schizophrenia

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ABSTRACT

Attention is a complex construct involving extensive interactions with working memory and executive control systems to process and extract meaning out of large amounts of multi-sensory information. Disruption of attention is a characteristic symptom in schizophrenia, and further studies on selective attention are crucial for understanding the disease. The current study looks at how subjects with schizophrenia selectively attend to either a visual or auditory metronome in the presence of asynchronous cross-modal distractors of 3 different frequencies (0.5, 1, and 2 Hz). Results showed that across all tasks of selective attention, patients with schizophrenia demonstrated increased variability in mean group reaction times compared to healthy volunteers. In addition, across all subjects (patients and controls), response times were most variable during the *attend visual* condition: a task in which subjects tapped in synchrony to a visual reversing checkerboard while ignoring an auditory metronome. Results also indicated that significantly more errors occurred in the highest (2 Hz) frequency condition. These findings are consistent with previous studies on healthy subjects showing that auditory distractors are more difficult to ignore than visual distractors during synchronized tapping. They are also consistent with studies revealing deficient selective attention in patients with schizophrenia. They do not, however, reveal any significant differences in patient vs. control performances during the auditory and visual conditions.

BACKGROUND

Attention is a complex construct involving extensive interactions with working memory and executive control systems (Luck and Gold, 2008) to process and extract meaning out of large amounts of multi-sensory information. Selective attention refers to the ability to attend to behaviorally relevant stimuli while ignoring irrelevant information (Johnson and Zatorre, 2005; Banich et al. 2000), and subsequently affects perception and action (Driver and Frackowiak, 2001). Many disorders, among them schizophrenia, affect various aspects of attention. Schizophrenia is a disorder of cognition, causing significant effects on attention, working memory, and executive functions (Rund and Borg, 1999; Heinrichs and Zakzanis 1998). Assessment of cognitive function provides valuable information about dysfunctional processing in schizophrenia, as it is correlated with functional skills and personal outcome (Bowie and Harvey, 2005). Because selective attention is the first step in the hierarchical concept of cognitive functioning, further studies on selective attention in schizophrenia are crucial to an understanding of the disease. The current study looks at how subjects with schizophrenia process selective attention to auditory and/or visual modalities in the presence of distracting stimuli in the other modality (auditory or visual). The intention is to try and delineate where deficits occur along the processing stream from sensory to higher cortical areas, as well as to compare differences in reaction times and error frequency during auditory and visual processing.

SELECTIVE ATTENTION IN HEALTHY SUBJECTS

Previous studies on selective attention to different sensory modalities in healthy participants have produced significant results that provide a framework for comparison with those studies concerning persons with schizophrenia. First, studies involving multisensory stimuli have shown that subjects perform tasks more slowly and less accurately when cross-modal distractors or non-matching multisensory stimuli are presented (Mayer and Kosson, 2004; Fan et al. 2002; Spence et al. 2004). Perception may be enhanced, however, when stimuli from multiple sensory modalities are temporally or spatially synchronous (Frith, 2001), or when stimuli convey semantically congruent or matching information. This phenomenon of multisensory integration also holds true when multisensory information is coming from different spatial locations, despite being temporally synchronous (Mozolic et al. 2007). A second consistent finding is that during tasks involving spatial attention in auditory or visual modalities, tasks presented in the unexpected modality (not preceded by cues) showed a reduction in processing efficiency compared to tasks in the unexpected modality. This observation is evidenced by slower response times and decreased accuracy for targets when they are presented in an unexpected modality (Spence et al. 2001). These behavioral findings have also been complemented by imaging studies demonstrating increases in activity in primary and secondary sensory cortices in response to stimuli of an attended sensory modality (Weissman et al. 2004; Talsma et al. 2006), with decreases in cortices of the unattended modality (Johnson and Zatorre, 2005). While studies have found consistencies in outside factors that facilitate or hinder selective attention, it is also important to review literature on the underlying brain network involved in selective attention.

THE ATTENTION NETWORK

The attention network is thought to consist of an anterior, frontal component and a posterior, parietal component. Activity in the frontoparietal networks is thought to directly cause modulation in sensory brain areas (Driver and Frackowiak, 2001). The frontal component is concerned with target detection, alerting, and motor representation, while the parietal component is involved with representation and orienting towards spatial locations (Kanwisher and Wojciulik, 2000). Specific areas within this fronto-parietal network produce top-down attention signals that instruct other areas in the system, such as the sensory cortices, to attend to certain features of a stimulus (Frith, 2001). This executive control of attention affects self-regulation of emotion and cognition and involves the participation of two important areas: the lateral prefrontal cortical regions and the anterior cingulate cortex (Wang et al. 2005). The dorsolateral prefrontal cortex (DLPFC) is thought to exert top-down control by directing attention to task-relevant information (Banich et al. 2000) and maintaining task-relevant information such as instructions, rules, and goals in working memory (Weissman et al. 2004).

The anterior cingulate cortex (ACC) is thought to detect conflict from distracting stimuli, and signals the DLPFC to increase attention towards task-relevant processing (Weissman et al. 2004). The ACC is thus activated when attending to more than one feature of a stimulus. While the DLPFC and ACC are the main frontal cortical areas studied in attention, the following table outlines other areas to emphasize that attention is a dynamic network involving the interplay of many cortical and subcortical areas.

Table 1. Cortical areas involved in visual and auditory selective attention

Structure	Function
Dorsolateral / Ventrolateral Prefrontal Cortices [1]	Important for attention processes (sustained, selective, divided) as well as executive functioning processes (inhibition and working memory)
Anterior Cingulate Cortex [1]	Involved in target and error detection, response selection and inhibition, performance monitoring, and motivation
Reticular Formation [1]	Sends input to the thalamus. Modulates attention and aids in filtering interfering stimuli
Hippocampus [1]	Processes and integrates multisensory input. Resolves conflicts between expectancies and current perception
Magnocellular Pathway [2]	Processes overall stimulus organization. Information projects from the retina to the primary visual cortex to the parieto-occipital cortex and other DORSAL stream areas
Dorsal stream [3]	Projects to frontal eye fields and DLPFC (BA 46). Exerts top-down feedback projection via prefrontal cortex
Parvocellular Pathway	Processes fine-grained stimulus configurations and object identifications
Auditory Cortex [4]	Located in superior temporal cortex. Involved in multisensory processing, as well as sound identity and location cues

References: [1] Filbey et al. 2008 [2] Butler et al. 2005 [3]Braus et al. 2002 [4]King et al. 2007

Multiple PET, fMRI, and EEG studies comparing DLPFC and ACC function in healthy subjects and patients with schizophrenia have shown decreased ACC (Carter et al. 1997; Carter et al. 2001; Neuhaus et al. 2006; Wang et al. 2005; Weiss et al. 2007) and DLPFC (Weiss et al. 2007) activity in patients with schizophrenia during tasks involving incongruent stimuli. Filbey et al. have also recently reported a decreased pattern of activation in prefrontal and parahippocampal areas despite unimpaired task performance in unaffected relatives (*presumed obligate carriers)* having both a parent and offspring with schizophrenia (Filbey et al. 2008). Another fMRI study on DLPFC dysfunction in schizophrenia has also shown significant correlations between the magnitude of DLPFC connectivity and behavioral performance during a continuous performance cognitive task involving letter cues (Yoon et al. 2008). A similar effect has been seen in ACC activity, as Weiss et al. (2007) showed a significant positive correlation between anterior cingulate activation and accuracy during a modified Stroop task in normal controls and patients with schizophrenia. In addition to imaging and behavioral studies showing ACC and DLPFC irregularity in schizophrenia, there is also histological evidence of a ‘mis-wiring' of dopaminergic fibers in layer II of anterior cingulate cortex of schizophrenic brains (Benes, 2000), as well as dysfunction of dopaminergic transmission in the DLPFC (Cohen and Servan, 1992). These results show that DLPFC and ACC dysfunction negatively affect selective attention in schizophrenia by reducing the ability to focus on a task, especially in the presence of significant distractors (Weiss et al. 2007).

OTHER FACTORS INVOLVED IN THE PATHOGENESIS OF SCHIZOPHRENIA

While findings of hypofrontality and reduced prefrontal cortex activity have been long-standing in research on attention in schizophrenia, they must be interpreted along with data on structural differences, neurotransmitter hypotheses, and abnormalities in sensory cortical regions. For example, MRI and CT studies examining neuroanatomical features of schizophrenia have consistently shown increased volume of the lateral and third ventricles, as well as smaller brain volumes, reduced hippocampal volume, and reduced neuropil in the dorsolateral prefrontal cortex (Flashman et al. 2004). These structural reductions must inevitably affect micro-scale processes such as metabolic activity and neurotransmitter receptors and subsequently synaptic activity. While past research has implicated the neurotransmitter dopamine in the cognitive deficits observed in schizophrenia, more recent interest has been directed to glutamate dysfunction in schizophrenia. Placebo-controlled trials with drugs that activate glutamate have shown reduced negative symptoms and improved cognition in patients simultaneously receiving atypical antipsychotics (Coyle et al. 2003). Noradrenergic pathways have also been implicated in the pathogenesis of schizophrenia, as Filbey et al. (2008) proposed that decreased right hemispheric activation in the fronto-temporo-parietal network of *presumed obligate carriers* of schizophrenia may reflect hypofunction of the right-lateralized noradrenergic pathways that function in vigilance. While structural and neurotransmitter abnormalities inevitably influence the abnormalities observed in the fronto-parietal network, questions remain as to whether reduced network activity in schizophrenia affects modulation of auditory and visual cortices involved in multisensory stimulus processing. Deficits have been observed in visual and auditory selective attention, but there is uncertainty as to where in the processing stream these disruptions occur: in the frontal lobe vs. along the frontotemporal neural pathways targeting sensory cortical regions vs. in the corticocortical connections linking individual sensory regions involved in early and late processing (Mathalon et al. 2004). Moreover, to what extent are these abnormalities the cause or result of other deficits?

AUDITORY AND VISUAL SELECTIVE ATTENTION IN SCHIZOPHRENIA

Functional MRI studies have found that in addition to decreases in modulation of cortical networks involved in attention, there are also abnormalities in visual and auditory processing in schizophrenia (Braus et al. 2002; Butler et al. 2005). In a study involving simultaneous visuoauditory stimulation, neuroleptic-naïve first-episode schizophrenic patients were found to have not only absent prefrontal area activation, but also decreased response in the right posterior thalamic relay nuclei that aid in the subcortical processing of sensory information. Patients also had bilateral hypoactivation of the dorsal visual processing pathway projecting to frontal eye fields and the DLPFC, and a reduced BOLD response in the left acoustic cortices of the temporal lobe (Braus et al. 2002), suggesting abnormalities in the sensory areas themselves in addition to the structures that aid in processing and relaying information to higher function cortical areas. Another modality used to study auditory and visual selective attention is event-related potentials, or ERPs. ERPs are generated in the brain as a result of synchronized activation of neuronal networks in response external stimuli, and are recorded at the scalp in the form of precisely timed sequences of waves (Kanwisher 2000). They allow for fast temporal resolution of stimulus-related neural activity, and are useful in elucidating when attentional deficits occur in the processing stream. Studies conducted on auditory selective attention in schizophrenia using event-related potentials (ERPs) have found evidence that cross-modal selective attention is present as early as

50 msec (Mathalon et al., 2004), but that waveform activity was reduced (Wood et al. 2007) or absent (Mathalon et al. 2004) by 100msec. Another study using mismatch negativity, an event-related potential index of auditory sensory memory, showed abnormal memory sensory processing that was significantly related to measures of negative symptoms (Catts et al. 1995). Mathalon et al. argue that the intact selective attention effects in the early stages of processing imply that some aspects of executive control are functioning normally. Deficits in sensory processing are therefore more likely downstream.

Electrophysiological studies on visual selective attention in schizophrenia have also showed reductions in ERP components representative of the early neural system activation supporting attention. One study reported that chronically ill, recent-onset, and chronic patients failed to generate a significant early color-related ERP component (P2a) during a visual (color) selective attention task (van der Stelt et al., 2006). Potts et al. (2002) showed reductions in N2b, an early ERP component reflecting perceptual processes on a target item, in addition to P2a abnormalities during a visual object-spatial attention task. Alain et al. (2002) also found smaller generated N2 waves in patients when compared with healthy subjects during tasks of visual attention. Butler et al. (2005) used steady-state visual evoked potentials in conjunction with MRI to not only show that early stage visual processing was impaired in general, but also found that evoked potential deficits were significantly related to decreased white matter integrity in optic radiations. While current fMRI and electrophysiological studies on selective attention have identified dysfunctional cortical areas and deficits in early processing in subjects with schizophrenia, further research using simplified cross-modal selective attention tasks needs to be performed in order to better delineate where deficits occur along the processing stream.

The current study examined how subjects with schizophrenia process selective attention to one sensory modality while ignoring a different distracting sensory modality during a task involving a significant temporal component. Patients and healthy controls were scanned during three different conditions, each of which involved tapping in synchrony to a steadily-paced metronome. The *multimodal attention* condition involved tapping in synchrony to both auditory (pure tone) and visual (reversing checkerboard) signals occurring simultaneously at the same frequency. In the *attend auditory* condition, subjects were instructed to attend and tap in synchrony with an auditory stimulus while ignoring the visual stimulus being presented at a different frequency. The *attend visual* condition involved subjects tapping in synchrony with the visual stimulus while ignoring the auditory distractor being presented at a different frequency. Each of the conditions were performed at three different frequencies to observe differences in reaction time and number of errors among patients with schizophrenia (SP) and healthy normal volunteers (HNV).

Studies involving attentional tasks have reported longer overall mean response times (Wang et al. 2005; van der Stelt et al. 2006), increased response times in incongruent trials (Banich, 2000), and less slowing of reaction time after error commission (Carter et al. 2001) among patients with schizophrenia when compared with controls. Patients with schizophrenia have also exhibited a higher frequency of errors during sensory incongruent trials (Carter et al. 1997), as well as decreased overall accuracy on tasks of attention (Wang et al. 2005; Alain et al. 2002) when compared with controls. Based on these previous findings, we predict that compared to healthy controls, patients with schizophrenia will have increased variability in mean reaction times and increased number of errors across all conditions. More specifically, patients with schizophrenia will exhibit the highest number of errors in the *attend* conditions (when confronted with incongruent stimuli) vs. the *multimodal* condition (when stimuli are temporally congruent), with the most errors occurring at the highest frequency (2Hz) attend conditions. MRI studies on auditory attention in schizophrenia have shown reduced cortical response to auditory stimulation in acutely ill patients (Braus et al. 2002) and others experiencing auditory hallucinations regardless of medication (David et al. 1996). Other studies have shown that the P300 component of auditory event related potentials is consistently reduced in schizophrenia, suggesting a diversion of attentional resources from orienting and directing attention to auditory stimuli (Mathalon et al. 2000). Based on these results, we can also hypothesize that patients with schizophrenia will be less affected by auditory stimuli presented as distractors in the *attend visual* condition, and will therefore have less variability in mean reaction times and a smaller percentage of errors in the *attend visual* when compared with the *attend auditory* conditions.

METHODS

Subjects

Sixteen patients with schizophrenia (SP) (15 male, 1 female) and 16 healthy normal volunteers (HNV) (15 male, 1 female) participated in the current experiment after obtaining proper informed consent according to institutional guidelines set forth by the University of New Mexico and New Mexico Department of Veterans Affairs. All SP were diagnosed using the Structured Clinical Interview for DSM-IV Axis-I Disorders, Clinician Version (SCID-CV), and were required to be stable on an atypical anti-psychotic medication [Aripiprazole (4), Ziprasidone (1), Risperidone (5), Quetiapine Fumarate (4), Olanzapine (2)] for at least three months to be included in the current study. SP exclusion criteria included a history of neurological disease, psychiatric hospitalizations within the previous six months, or history of substance abuse within the past year. HNV with a history of major medical conditions, neurological disease, significant psychiatric disturbance, substance abuse, or psychoactive prescriptive medications were also excluded from the current study. One HNV was identified as an outlier (three standard deviations above the mean) on several behavioral measures and was therefore excluded from further analyses. There were no significant differences ($p > 0.10$) between SP and HNV populations for all major demographic categories, including age (SP: 40.2 +/- 8.2, HNV: 40.1 +/- 8.8), education (SP: 12.6 +/- 2.4, HNV: 13.0 +/- 1.4), or handedness (SP: 77.7 +/- 56.1, HNV: 67.3 +/- 68.9) as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971).

Task

The subjects were required to participate in six visual and/or auditory attention tasks of 8-second duration each, in which the stimuli were presented at the same or different standard intervals (0.5 Hz / 2000 ms; 1 Hz / 1000 ms; or 2 Hz / 500 ms) depending on the condition. Tasks of visual attention involved participants tapping fingers of both hands in synchrony with a reversing checkerboard (visual angle = 19.42 degrees x 14.88 degrees; duration = 100 ms). Tasks of auditory attention involved tapping in synchrony to a pure tone (1000 Hz with a 10 ms linear rise and fall; duration = 100ms). Each task was preceded by a 500 Hz tone and pictogram (visual cue) indicating whether participants should tap in synchrony to auditory, visual, or both stimuli presentations. Following the tone and cue, a baseline fixation cross was presented for 1 second prior to the onset of the 8-second block.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Figure 1. Table adapted from Mayer AR, Franco A, Canive J, & Harrington J
The Effects of Stimulus Modality and Frequency of Stimulus Presentation on C
Cross-modal Distraction. Cerebral Cortex 2008.

Diagrammatic representation of the multimodal condition. Each trial began with a variable fixation period, followed by the presentation of a cue (eye, ear, or hand) indicating the modality or modalities for focused attention. The auditory (tones) and visual (reversing checkerboard) stimuli were then presented for 8 s. The amount of time between successive target stimuli varied between 500 and 2000 ms, corresponding to stimulus presentation rates of 0.5, 1, or 2 Hz. Stimuli were presented at either different (the attend conditions) or the same (the multimodal condition) rate in the auditory and visual modalities. The background color of the screen and the fixation cross has been reversed in this cartoon to facilitate presentation.

The study involved three main conditions presented across six 8-second runs: *multimodal attention*, *attend-auditory*, and *attend-visual*. The *multimodal attention* condition involved participants tapping in synchrony to both visual and auditory stimuli presented simultaneously at the same frequency (0.5, 1, or 2 Hz). The *attend* conditions involved participants attending and tapping to a stimulus in the specified modality, while ignoring the distracting stimulus in the other modality (auditory or visual). Stimuli in the unattended modality were presented at a different frequency than those in the attended modality, ensuring that the ignored stimulus occurred both in and out of phase with the target stimulus across each trial (for a total of 12 different trial types in the attend conditions). The unsynchronized nature of the *attend auditory* and *attend visual* conditions also provided an objective measure of examining how effectively subjects were attending to the target modality, as well as whether it was easier to focus on visual or auditory tasks.

Table 2. Study design Table adapted from Mayer AR, Franco A, Canive J, & Harrington JA. (2008) The Effects of Stimulus Modality and Frequency of Stimulus Presentation on Cross-modal Distraction. Cerebral Cortex 2008.

Attention Conditions	Stimulus Types				
	Attended Modality	Ignored Modality	Rate (Hz) of Attended / Ignored Stimuli		
Multimodal Attention	Auditory & Visual		.5	1	2
Auditory Attention (A)	Auditory	Visual	.5 /1	1 /.5	2 /.5
Auditory Attention (B)	Auditory	Visual	.5 /2	1 /2	2 /1
Mean [1]	Auditory	Visual	.5 /1.5	1 /1.25	2 /.75
Visual Attention (A)	Visual	Auditory	.5 /1	1 /.5	2 /.5
Visual Attention (B)	Visual	Auditory	.5 /2	1 /2	2 /1
Mean [1]	Auditory	Visual	.5 /1.5	1 /1.25	2 /.75

[1] In the multimodal attention condition, auditory and visual stimuli were presented simultaneously at the same rate (Hz). In the auditory and visual selective-attention conditions, the rates of attended and ignored stimuli were averaged across two trials (A + B/2) based on the attended stimulus rate to form a single condition. Thus, the mean rate of attended stimuli remained at .5, 1 and 2 Hz whereas the mean rate of ignored stimuli was an average of two rates (i.e., mean of 1 and 2 Hz for the ignored stimulus at the .5 Hz attended rate = 1.5 Hz; mean of .5 and 2 Hz for the ignored stimulus at the 1 Hz attended rate = 1.25 Hz; and mean .5 and 1 Hz for the ignored stimulus at the 2 Hz attended rate = .75 Hz).

The entire experiment occurred in the context of a functional magnetic resonance imaging (fMRI) experiment. However, the current proposal focuses only on the behavioral data. Visual stimuli were rear-projected using a Sharp XG-C50X LCD projector on an opaque white projection screen, while auditory stimuli were presented via an Avotec SS-3100 audio system. Neurobehavioral systems Presentation software was used for stimulus presentation, synchronization of the MRI scanner with stimulus events, and response time collection. Software limitations restricted recording to only responses from subjects' right index finger.

Statistical Analysis

As part of the analyses, the multimodal and selective attention conditions were directly compared with stimulus frequency between SP and HNV. Two separate 2x3x3 mixed-measures ANOVAs (analysis of variance) were conducted for the coefficient of variation (COV) and error data as the dependent variables. The within subject factors were attention condition (multimodal, attend auditory, attend visual) and attended stimulation rate (0.5, 1, or 2 Hz), and the between subjects factor was group (patients with schizophrenia compared to controls). COV is a measure of variability (#51: Boslaugh and Watters, 2008), and for this study represented the amount of interference from cross-modal distractors. It was computed by dividing the amount of time that elapsed between successive button presses (i.e. intertap interval) by its respective standard interval (500ms, 1000ms, or 2000ms). A higher COV therefore indicates more interference during the intertap intervals, meaning a more variable performance (i.e., participants were not as effective at tapping in synchrony with the metronome). The COV is thus a measure of processing efficiency (Spencer and Ivry, 2005), and in this study provides a measure of the impact of cross-modal distractors on processing efficiency (Mayer et al. 2008; Repp and Penel 2004).

RESULTS

A 2 x 3 x 3 [Group (SP vs. HNV) x Attention Condition (*multimodal, attend-auditory, attend-visual*) x Frequency (.5, 1, 2Hz)] mixed-measures ANOVA was performed to evaluate the hypothesis that out of the three conditions, SP reaction times will be the most variable in the attend auditory condition. Analyses of COV demonstrated a significant main effect of condition ($F_{2, 58} = 30.5$, $p < .001$), main effect of group ($F_{1,29} = 7.8$, $p < .01$), and a significant condition by frequency interaction ($F_{4,116} = 6.8$ $p < .001$); however, the group by condition interaction was not significant. A non-significant trend was also observed for the main effect of frequency ($F_{2, 58} = 2.9$, $p = .06$). Examination of group means suggested that SP (mean = .18) demonstrated increased variability (higher COV) compared to HNV (mean = .15). Follow-up analyses of the main effect of condition showed that response times were most variable in the *attend-visual* condition (mean=.192) compared to both the *attend-auditory* (mean=.164; $t_{30} = 4.4$, $p < .001$) and *multimodal* conditions (mean=.147; $t_{30} = 8.1$, $p < .001$). The *attend-auditory* was also significantly more variable than the *multimodal* condition ($t_{30} = 3.3$, $p < .005$).

The next sets of analyses were conducted to further examine the significant condition x frequency interaction. Three one-way ANOVAs indicated that the main effect of condition was significant ($p < .001$) at each Hertz (.5, 1 and 2). Pair-wise comparisons indicated that the coefficient of variation was significantly greater (all *p's* < .001) for the *attend visual* compared to *multimodal* condition at all three frequencies, and significantly greater (all *p's* < .05) for the *attend visual* compared to *attend auditory* condition at .5 and 2 Hz. In contrast, the coefficient of variation was significantly greater (all *p's* < .05) for the *attend auditory* compared to multimodal condition only at 1 and 2 Hz.

An identical 2 x 3 x 3 [Group (SP vs. HNV) x Attention Condition (multimodal, attend-auditory, attend-visual) x Frequency (.5, 1, 2Hz)] mixed-measures ANOVA was performed separately to evaluate the hypothesis that SP would exhibit a greater number of incorrect responses across all conditions, with the most errors occurring during the *attend auditory* condition. Results indicated a significant main effect for frequency ($F_{2, 58} = 13.9$, $p < .001$) and condition by frequency interaction ($F_{4,116} = 2.5$, $p < .05$), but not for condition or group. Further analyses of the main effect of frequency revealed that significantly more errors occurred at 2 Hz (mean=.003) compared to both .5 (mean=.0008; $t_{30} = 4.3$, $p < .001$) and 1 Hz (mean=.002; $t_{30} = 2.4$, $p < .05$). In addition, more errors also occurred at 1 compared to .5 ($t_{30} = 4.2$, $p < .001$) Hz. Three one-way ANOVAs were conducted to further assess differences between the three attention conditions at each frequency (condition by frequency interaction). However, there was only a trend ($p = .054$) for a significant effect of condition at 2 Hz.

DISCUSSION

This study looked at how patients with schizophrenia process information in one sensory modality while ignoring distracting information presented in a different sensory modality. Results showed that across all tasks of selective attention, patients with schizophrenia (SP) demonstrated increased variability (higher COV) in mean group reaction times compared to HNV. In addition, response times were most variable across all subjects in the *attend-visual* condition, during which subjects tapped in synchrony to a visual reversing checkerboard while ignoring an auditory metronome. These findings are consistent with previous studies on healthy subjects showing that auditory distractors are more difficult to ignore than visual distractors during synchronized tapping (Mayer et al. 2008; Repp and Penel 2004; Kato and Konishi 2006). Results also showed that across all conditions and participants, significantly more errors occurred in the 2 Hz frequency condition.

SP DEFICIENCIES ACROSS ALL TASKS

Current findings can be interpreted in the context of previous studies on schizophrenia that provide anatomical, neuronal, and pathway-specific explanations for disturbances in visual and auditory perception. Many studies have documented difficulties in integrating visual information (Butler et al. 2008), impairments in smooth-pursuit eye movements (Holzman, 1987), and impairments in motion perception (Chen et al. 1999; Brenner et al. 2003) in schizophrenia. In an fMRI study involving auditory and visual activation to examine basic sensory input circuits in neuroleptic-naïve first-episode schizophrenic patients, Braus et al. (2002) found abnormal functioning of the thalamus and high-order frontoparietal cortical areas restricted to the dorsal visual processing stream. The dorsal visual stream conducts low-resolution visual information rapidly to the cortex (Butler et al. 2005; Steinman et al. 1997). It receives input from the magnocellular system, which is thought to be involved in attentional capture and processing of stimulus organization. The frontal and parietal regions implicated in the dorsal visual stream are similar to those activated during attention to visual motion and smooth-pursuit eye movements (Butler et al. 2002), and suggest that the dorsal visual processing stream is an anatomical correlate of the well-documented visual deficits observed in schizophrenia. While these studies suggest anatomical and pathway specific dysfunction of visual attention, Butler et al. propose that the observed symptoms reflect impaired neurotransmission at NMDA-type glutamate receptors. This observation thus implies that the underlying visual deficits observed in schizophrenia may be due to processing characteristics instead of specific pathways (Butler et al. 2005). The results of these studies enforce the idea of diffuse cortical and subcortical pathology accounting for disturbances in visual and auditory attention.

Studies on auditory selective attention in patients with schizophrenia also provide theories of disconnectivity and neurotransmitter dysfunction. In an ERP study assessing the integrity and time course of auditory attention in schizophrenia during a cross-modal selective attention task, Mathalon et al. (2004) found that patients with schizophrenia showed evidence of selective attention at the earliest attention modulated component, but not at later components. These findings imply initially intact executive control of auditory attention which then becomes disconnected in the relay from the frontal lobes to the auditory cortices. Another study comparing high level (attention and context processing) to earlier low level (perceptual discrimination and organization) auditory temporal processing in schizophrenia also found abnormalities with later, more complex, higher stages of processing (Bourdet et al. 2003). Specifically, these more problematic tasks included detection of local temporal irregularities within a stream, as well as attentional focusing on one stream using a preceding cue. While the previous two studies have found deficits specifically in the later modulation of auditory attention, other fMRI studies concerning auditory selective attention in schizophrenia have found reduced activation of cortical and subcortical structures subserving attention (Kiehl et al. 2005; Menon et al. 2001), as well as reduced connectivity between these regions (Schirmer et al. 2009; Kim et al. 2009). Yet another possibility of auditory attention deficits involves the compromised integrity of some neuronal groups within the auditory cortex, specifically abnormal glutamatergic neurotransmission at NMDA receptors in auditory cortex neurons (Mathalon et al. 2004). As with visual processing deficits, there are many possible causes of auditory processing deficits in schizophrenia.

The current study reinforced previous findings of SP deficits in selective attention, in the form of increased variability in reaction times irrespective of modality. In addition to the previously mentioned reasons for dysfunction, recent research is also exploring the “default mode”. The default mode is the brain’s baseline activity involved in introspection and self-referential thoughts, and is believed to exhibit delayed deactivation in patients with schizophrenia. Perhaps the observed findings reflect difficulty in patients' ability to shift away from their baseline activity and modulate other networks related to the task at hand (Kim et al. 2009). The variability in reaction times may also be accounted for by a motor dysfunction, as a recent fMRI study preliminarily found excessive hemodynamic activity in bilateral motor cortices in schizophrenic patients suggestive of abnormal coordination of motor behavior (Kiehl et al. 2009). It is important to note that while patients had increased variability in mean reaction times across all tasks, they did not have a significant difference in number of errors when compared to controls, contrary to what was hypothesized. A likely explanation may be that when looking at behavioral results, the reaction times are typically more sensitive than error frequency.

INCREASED VARIABILITY IN *ATTEND VISUAL* CONDITION

While the SP's were overall deficient in tasks of selective attention, they did not perform more poorly in the *attend auditory* when compared with the *attend visual* conditions, as hypothesized. Previous imaging and ERP studies have found more pronounced deficits in auditory attention in acutely ill patients (Braus et al. 2002), those experiencing auditory hallucinations (David et al. 1996), and significantly related to measures of positive (Turetsky et al. 1998; Mathalon et al. 2000) and negative symptoms (Catts et al. 1995; Turetsky et al. 1998). One explanation for the observed results may be that the patients were all asymptomatic and on atypical antipsychotics at the time of testing, and were therefore able to focus and complete the tasks more effectively. The SP's neuroleptic medication may have buffered these frequently observed findings enough to mask significant problems with auditory attention.

INCREASED ERROR FREQUENCY AT 2 HZ

Analysis of the effects of stimulus frequency revealed that across all conditions, patients and controls had more errors during visual and auditory tasks presented at a higher frequency. A basic explanation for these findings may be due to increased muscle fatigue when tapping to stimuli presented at a higher frequency. Another explanation may involve the anterior cingulate cortex's (ACC) ability to monitor conflict from distracting stimuli during information processing. It is thought that in the context of stereotyped and habitual responses, conflict arises whenever infrequent responses are required. The ACC response is therefore consistently greater for low-frequency than high frequency responses (Braver et al. 2001), and across all subjects may have played a part in increased accuracy at lower frequency tasks.

While statistical analyses of task error showed a main effect of frequency, they did not reveal a significant main effect for condition or group. This result differs from those of other studies on task completion in schizophrenia, including Butler et al.'s (2008) finding that when compared with controls, patients with schizophrenia exhibited a greater number of errors when given less time to complete an object discrimination task. As a group they also needed significantly more time than controls to perform at 70%. One can extend the argument that in the SP's, these problems with task completion would have been exacerbated when expected to detect a target at a higher frequency and in the presence of cross-modal distractors. The lack of similar findings in the present study could be due to various demographic and medication-related factors.

As previously alluded to, a limitation to the experiment may be that the SP's were medicated with no active symptoms, and may have performed differently had they not been on neuroleptics. Nevertheless, absence of medication poses other problems such as compliance and the ability of the patient to relate symptoms such as visual and/or auditory hallucinations. Yet another potential bias was the completion of a task involving a significant temporal component (i.e. tapping to a visual metronome), which studies have shown creates more difficulty in ignoring auditory rather than visual distractors (Mayer et al. 2008; Kato and Konishi 2006; Repp and Penel 2004). This behavior is substantiatied by the obligatory recruitment of auditory cortical areas during synchronized tapping, regardless of attention task (Mayer et al. 2008).

One of the challenges in the design of studies on selective attention in schizophrenia involves taking into consideration the severity of symptoms, rate of stimulus presentation, and the complexity of the tasks involved. Future studies should separate tasks and complexities by perhaps evaluating synchronous tapping to unimodal metronomes with and without cross-modal distractors. They could also use a less complex visual stimulus to see if that has any effect on paced tapping to auditory vs. visual metronomes. Modalities such as fMRI also provide more information by correlating brain activation with task components. The results of the current study reinforce previous observations of impairments in visual and auditory selective attention in schizophrenia. They make more apparent the need for further analysis of the dynamic nature of deficits, which cannot yet be isolated to definite processing characteristics, specific pathways, or connections between the pathways.

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