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EVENT RELATED BRAIN POTENTIAL EVIDENCE FOR PRESERVED *ATTENTIONAL* SET SWITCHING IN SCHIZOPHRENIA

Paul D. Kieffaber¹, Brian F. O'Donnell^{1,3}, Anantha Shekhar^{2,3}, and William P. Hetrick^{1,3}

¹ *Indiana University Bloomington*

² *Indiana University School of Medicine*

³ *Larue D. Carter Memorial Hospital*

Abstract

Pervasive deficits of attention and set switching have been reported in schizophrenia, prompting efforts to identify the information processing mechanisms associated with these deficits. Recent evidence suggests that set switching may be intact in schizophrenia when the task switch requires only a change in the relevance of perceptual dimensions (e.g., attentional set switches) but decision-to-response mappings (intentional set) are maintained across trials in a cued task switching procedure. The goal of the present research was to replicate this finding and to test its direct corollary, which is the unconventional prediction that individuals with schizophrenia will evidence an intact, switch-sensitive P3b brain response to cued switches of attentional set. This prediction was tested in a group of 20 individuals with schizophrenia and 20 healthy comparison participants using event-related brain potential methodology and a cued task-switching task. Attentional set switching costs were equivalent between the two groups despite a set maintenance deficit in schizophrenia. Moreover, a posterior-parietal P3b component of the ERP was found to be equally sensitive to attentional set switching in schizophrenia and comparison groups, indicating a “healthy” brain response to switches of attentional set in schizophrenia. These results suggest that the dynamic control of attentional set may be preserved in schizophrenia and that previously reported executive deficits may be specific to the control of intentional task set and to deficits of task set maintenance.

Disorders of “executive” or controlled attention are integral to even the earliest characterizations of schizophrenia (Bleuler, 1911; Kraepelin, 1919). In contemporary research, the ability to switch between two or more tasks is commonly used as a measure of cognitive control. Historically, research into this central aspect of the disorder has relied heavily upon measures of cognitive performance drawn from neuropsychological assessments like the Wisconsin Card Sorting Task. Whereas the ability of these traditional neuropsychological tests to discriminate normal from abnormal brain functioning is well-established, these tasks recruit a broad range of cognitive processes, leading to considerable debate over the nature of attentional dysfunction in schizophrenia (e.g., Li, 2004; Smith et al., 1998).

In an effort to address the shortcomings of conventional neuropsychological assessments, some investigators have employed set switching tasks (Kieffaber et al., 2006; Meiran, Levine,

Correspondence: Paul Kieffaber, Carnegie Mellon University, Department of Psychology, Baker Hall 345I, 412.268.5027, pkieffab@andrew.cmu.edu

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Meiran, & Henik, 2000). Task set refers to a transient configuration of perceptual, cognitive, and response biases that facilitate the performance of task-appropriate behavior (See Gibson, 1941;Shakow, 1962). As discussed below, a number of important conceptual distinctions have emerged from the task switching literature, including distinctions between task *set maintenance* and task *set switching* and the distinction between *attentional* and *intentional* components of task set.

Task set maintenance refers to the ability to regulate the impingement of competing, task-irrelevant information on ongoing information processing. Early research suggested that individuals with schizophrenia are impaired in their ability to maintain task set (e.g., Huston, Shakow, & Riggs, 1937;Rodnick & Shakow, 1940;Shakow, 1962). The Stroop effect, which has also been shown to be exaggerated in individuals with schizophrenia (e.g., Barch et al., 1999;Henik et al., 2002;McNeely, West, Christensen, & Alain, 2003), is a good example of how irrelevant, response-incongruent information can burden ongoing processing and interfere with the maintenance of a relevant task set.

Task set switching refers to the ability to dynamically reconfigure task set. In healthy participants, responses are typically longer and more error-prone immediately following a task switch and these “switch costs” are a common index of cognitive control in task set switching. A widely used index of task switching dysfunction in schizophrenia is performance on the WCST. An increased number of perseverative errors is a common finding in individuals with schizophrenia and is often interpreted as an inability to switch task set from a previous to a current sorting rule (e.g., Crider, 1997;Everett, Lavoie, Gagnon, & Gosselin, 2001;Koren et al., 1998). As noted previously, however, while the WCST clearly indicates a disturbance of attention in schizophrenia it lacks the precision needed to inform questions about the nature of the information processing mechanisms that elicit the dysfunction.

A number of candidate information processing mechanisms have already been proposed and these are often articulated in terms of their role with respect to either sensory/perceptual or response-delegation processes (e.g., Barch et al., 1999;Crider, 1997;Elliott, McKenna, Robbins, & Sahakian, 1998;Everett, Lavoie, Gagnon, & Gosselin, 2001;Henik et al., 2002). In the task switching literature, sensory/perceptual processes are regarded as those related to the discriminative selection of stimuli or stimulus features and are sometimes referred to as “attentional set” whereas response-delegation processes are regarded as those that govern the application of rules related to the selection and/or execution of motor responses and are sometimes referred to as “intentional set” (Kopp, Tabeing, Moschner, & Wessel, 2006;Rushworth, Passingham, & Nobre, 2002).

The concepts of attentional and intentional set also have been distinguished in studies of event-related brain responses to switches of task set. A common finding is that a posterior, late (i.e., 600–800 ms), positive component of the ERP corresponds with the attentional set switch (Hsieh, 2002;Karayanidis, Coltheart, Michie, & Murphy, 2003;Kieffaber & Hetrick, 2005;Rushworth, Passingham, & Nobre, 2002). In some cases, both parietal and frontal cortical regions are implicated during a preparatory interval. Because switch trials often require both a change to perceptual processing biases and the appropriate response alternatives, parietal and frontal activations are sometimes interpreted to reflect the attentional and intentional components of task set respectively (Drew J. A. Moulden et al., 1998;Rushworth, Passingham, & Nobre, 2002).

Whereas conventional stimulus-locked ERP averages are thought to index early perceptual encoding and identification, event-related lateralizations such as the lateralized readiness potential (LRP) reflect the latency and integrity of late stimulus evaluation and early response selection. When it is time-locked to response execution, the LRP is assumed to index motoric

processing and can vary with factors such as response accuracy (van Schie, Mars, Coles, & Bekkering, 2004). There is evidence that both set switching (Hsieh, 2006) and set maintenance (Masaki, Takasawa, & Yamazaki, 2000) effects are reflected in the stimulus-locked rather than the response-locked LRP. These findings are consistent with the idea that intentional processes governing early response selection could be a source of the corresponding behavioral task set switching effects as well as for set switching deficits in schizophrenia.

Despite the ample evidence for broad deficits of attention and context processing (including task switching) in schizophrenia, recent research using task switching procedures suggests that these deficits may be specific to the “intentional” subset of information processing mechanisms. For example, Meiran et al. (2000) found that individuals with schizophrenia were intact in their ability to engage a task set and that schizophrenia-like performance deficits could be induced in healthy control participants by manipulating parameters of the task responses (i.e., intentional set). Additionally, Barton et al., (2005) demonstrated intact set switching in an antisaccade task by people with schizophrenia and suggested that their performance was more indicative of abnormal persistence in the saccadic response system. Finally, Kieffaber et al. (2006) demonstrated that set switching is intact in schizophrenia when task switches comprise a change to the relevance of perceptual dimensions (i.e., attentional processes) but do not include a change to the decision-to-response mappings (i.e., intentional processes). Critically, this claim that attentional set switching is preserved in individuals with schizophrenia leads to the unconventional prediction that individuals with schizophrenia will also exhibit the expected switch-sensitive, P3b brain response following a cue to switch attention. Thus, the primary aim of the present study was to replicate and extend the finding of preserved attentional set switching in schizophrenia using a cued task switching paradigm and event-related potential (ERP) methodology.

Consistent with previously published findings (Kieffaber et al., 2006), it was predicted that that participants with schizophrenia would exhibit switch costs equivalent to those produced by healthy control participants. Critically, it was predicted that participants with schizophrenia would also exhibit an intact posterior-parietal P3b component of the ERP following a cue to switch attention. Despite this predicted equivalency in set switching, it was also predicted that set maintenance deficits in schizophrenia would be evident in greater reaction time delays to incongruent compared with congruent trials. Taking previous electrophysiological and clinical research into consideration, a number of other hypotheses related to the set maintenance effects in the target-locked ERP components could also be articulated.

Target-locked processing was assessed by both a conventional analysis of target-locked ERP amplitudes and an analysis of the lateralized readiness potential (LRP), time-locked to both the stimulus and the response. To the extent that set maintenance costs reflect impaired perceptual processing in the face of conflicting, incongruent information, differences between the conventional stimulus-locked ERP averages would be expected to be manifest in the comparison between congruent and incongruent trials. However, if the performance by participants with schizophrenia is undermined by impaired decisional and/or response-delegation processes, then differences will be most prominent in the amplitudes and/or time-courses of the lateralized readiness potentials on congruent and incongruent trials.

Methods

Participants

Twenty seven individuals meeting DSM-IV (American Psychiatric Association, 1994) criteria for schizophrenia and 22 healthy comparison participants were recruited and tested. Exclusion criteria included cardiovascular or neurological disease, head injury resulting in loss of consciousness, meeting DSM-IV criteria for substance dependence within the previous three

months, and meeting diagnostic criteria for current DSM-IV Axis I mood or anxiety disorder. Seven participants with schizophrenia and two healthy comparison participants were removed from the analysis due to poor task performance defined as an accuracy rate lower than 60%. Excluded participants did not differ significantly from included participants with respect to switch or maintenance costs in the task. Thus, 20 non-psychiatric and 20 patients were included in data analyses. Participants were between 20 and 65 years of age (mean age = 40.4/45.0, SD = 13.2/10.3 for the control/schizophrenia groups respectively). Further details regarding demographic and clinical symptoms are presented in the Supplementary Materials.

Set Switching Task

A schematic of the set switching task is shown in Figure 1. Participants judged pairs of figures that varied in shape (circles, squares, and triangles) and size (small [0.45° of visual angle], medium [0.86°], and large [1.59°]), indicating by button response whether the two stimuli were “same” or “different” according to a given rule (i.e., shape or size). Response mappings (e.g., left button = “same”; right = “different”) were maintained within, but counterbalanced across participants. The operative rule was indicated by a spoken cue (i.e., “shape” or “size”; 365ms duration at 70dB SPL), presented using insert earphones 1200 ms before the onset of the target figures. Target stimuli were presented for 400 ms on a standard CRT monitor and could be either “congruent” (e.g., two large squares) or “incongruent” (e.g., large square and small square) with respect to the correct response on the currently relevant dimension. The paradigm consisted of three blocks of 120 trials with a short break permitted between each block. “Switch” trials could occur after one ($N=90$), two ($N=45$), or four ($N=45$) consecutive trials of the previous rule, yielding an experientially random trial sequence in which the global probability of a task switch was 0.5 and the conditional probability of a task switch was also 0.5 on the majority (75%) of trials (See Kieffaber & Hetrick, 2005). All possible trial types were equally represented. A 3000 ms response window was provided; however, a response terminated the response window. Following a response, feedback was immediately displayed for 500 ms and the subsequent trial began 1500 ms thereafter. Response time (RT) outliers, defined as those that were more than twice the interquartile range above or below the third and first quartiles, were identified within each condition for each participant and were removed prior to the analysis.

Electrophysiological Apparatus

Electroencephalographic recordings were made with 29 Ag-AgCl sintered electrodes (10–20 system) and bioamplification system (Neuroscan Inc., Sterling VA.). Data were sampled at 1KHz with gain of 10K, and an analogue bandpass filter of 0.1 to 200 Hz. Vertical and horizontal eye movements were recorded (gain = 5K). Cortical leads were referenced to the tip of the nose and all impedances were maintained below 10 k Ω .

Signal Processing

EEG data were analyzed offline using Matlab 6.1 (The MathWorks, Natick, MA). The continuous data were segmented from –100 to 1200 ms relative to stimulus onset for both the cue and target. Trials containing muscular artifact and/or voltage values at the maximum A/D range were excluded. The data were corrected for ocular artifact using independent components analysis (Jung et al., 2000) and baseline corrected over the pre-stimulus interval. The segmented cue and target data were averaged across trials, within conditions for each participant. Cue- and target-locked ERP data were quantified by spatiotemporal principal components analysis (SPCA) (Spencer, Dien, & Donchin, 1999). Spatiotemporal principal component scores (μ V-scaled) were submitted to repeated measures analysis of variance. Details of the SPCA and identification of spatiotemporal components can be found in the Supplementary Materials. In the interest of parsimony, ERP component scores were designated

by the conventional name of the ERP component to which they correspond and followed by an asterisk.

Based on previous research (e.g., Karayanidis, Coltheart, Michie, & Murphy, 2003; Kieffaber & Hetrick, 2005; Drew J.A. Moulden et al., 1998) with task-switching paradigms, the P3a, and P3b components of the late positive complex were of primary interest in the analysis of both the cue-target and target-locked intervals. Although there is some debate about the number and nature of the various sub-components that constitute the late positive complex, the present designation of P3a and P3b corresponds with the time-course (i.e., 300–1000 ms) and respective anterior and posterior spatial distributions of these component waveforms observed in the literature (Dien, Spencer, & Donchin, 2004; Makeig et al., 1999). In addition to these components of the late positive complex, other conventional ERPs (e.g., N1 and P2) were also taken into consideration. In addition to permitting a more complete evaluation the selectivity of the experimental effects, consideration of these early ERP components will permit meaningful comparisons between the patient and healthy comparison groups with respect to early perceptual processing and encoding of task stimuli. The analysis of the cue-target interval included the factors of Switch (switch/non-switch) and Diagnosis (Schizophrenia/Non-psychiatric control) and the analysis of the target-locked interval included the factors of Switch, Congruency (congruent/incongruent) and Diagnosis.

Target and response-locked LRP waveforms were defined on the homologous electrode pairs C₃ and C₄ as

$$LRP = \frac{1}{2}[(C_4 - C_3)_L + (C_3 - C_4)_R]$$

where *L* and *R* index the lateralization with respect to the left and right hand responses (Oostenveld, Stegeman, Praamstra, & van Oosterom, 2003). Thus, positive deflections in the LRP reflect increased amplitudes in the hemisphere contralateral to the correct response. LRP onset latencies and peak amplitude/latencies were quantified using a jackknife-based scoring method (Miller, Patterson, & Ulrich, 1998; Ulrich & Miller, 2001). Peak LRP amplitude and latency were defined at the point of maximum positive deflection in the 1200 ms LRP window and onset latencies were defined using a 50% criterion in jackknife averages after being smoothed with a 10-Hz low-pass filter. Because the error variance in the means of the subsample scores derived from the jackknife procedure is artificially reduced, corrected *F*-values (*F_c*) were used in the analysis of LRP amplitude and latency (Ulrich & Miller, 2001). Onset and peak latencies, and peak amplitudes were each submitted to separate repeated measures ANOVA with Switch and Congruency as within-subject (i.e., jackknife average) factors and Diagnosis as a between subject factor.

Results

Accuracy and Response Time

Response accuracy—Performance data from the set switching task is summarized for each group in Figure 2. Overall performance on the task was very good; however, accuracy rates were lower in the schizophrenia group, $F(1, 38) = 22.66, p < .05, \eta^2 = 0.39$. Response accuracies for each condition were entered into a Switch (2) by Congruency (2) by Diagnosis (2) mixed model ANOVA. Switch costs approached significance in the accuracy rates $F(1, 38) = 3.64, p = .06, \eta^2 = 0.09$, however, maintenance costs were clearly evident in reduced accuracy rates in the incongruent compared with the congruent condition, $F(1, 38) = 33.98, p < .05, \eta^2 = 0.39$. Moreover, a set maintenance deficit was evident in the schizophrenia group as indicated by a significant Congruency by Diagnosis interaction, $F(1, 38) = 16.04, p < .05, \eta^2 = 0.18$.

Response latency—RT data from correct trials were submitted to an ANOVA equivalent to that used with the accuracy data. Overall mean RTs were longer in participants with schizophrenia, $F(1, 38) = 8.29, p < .05, \eta^2 = 0.18$. Switch trials were associated with significant switch costs, $F(1, 38) = 24.80, p < .05, \eta^2 = 0.39$. However, switch costs were comparable between the schizophrenia and healthy comparison groups (i.e., non-significant Switch $\times$ Diagnosis interaction). RTs were significantly longer to incongruent than congruent targets, $F(1, 38) = 96.11, p < .05, \eta^2 = 0.67$ and a significant interaction between Congruency and Diagnosis indicated a set maintenance deficit in participants with schizophrenia, $F(1, 38) = 9.61, p < .05, \eta^2 = 0.07$. Finally, the relationship between set switch and set maintenance was further evaluated by measuring the direct association between switch (e.g., switch-stay) and maintenance (e.g., incongruent-congruent) costs. There was no evidence for a significant relationship between switch and maintenance costs in either participant group or in aggregate, $r(40) = 0.12, p = \text{NS}$.

Cue ERPs

The conventional grand average ERPs for switch and non-switch trials are displayed for a subset of midline electrode sites in Figure 3. The results of the PCA, suggested the retention of three spatial and nine temporal components, which are displayed in Figure 1 of the Supplementary Materials. Four conventional ERPs were identified. The N1, P2, and P3_a components are visible over fronto-central recording sites during the interval between approximately 50 and 450 ms. Finally, the P3_b component is identifiable by its posterior distribution and time-course between approximately 400 and 1000 ms. The amplitudes of each of these components for each of the experimental conditions and groups are displayed in Figure 4.

N1*—N1* amplitudes were equivalent between SZ and HC groups. Moreover, there were no significant task-related amplitude differences in this component.

P2*—P2* amplitudes were equivalent between SZ and HC groups. There was a switch-related increase in the amplitude of P2*, $F(1, 38) = 11.08, p < .05, \eta^2 = 0.23$ but this effect did not vary between diagnostic groups.

P3_a*—There were no significant differences in P3_a* amplitudes across conditions or diagnostic status.

P3_b*—P3_b* amplitudes were considerably larger for the HC group, $F(1, 38) = 7.86, p < .05, \eta^2 = 0.17$. Moreover, P3_b* amplitude showed the predicted switch sensitivity (e.g., switch>stay), $F(1, 38) = 9.81, p < .05, \eta^2 = 0.19$. Critically, this amplitude sensitivity of the P3_b* to cued task switches did not significantly differ between SZ and HC groups.

Target ERPs

Conventional ERPs—The conventional, target-locked grand average ERPs for switch and non-switch trials are displayed for a subset of the electrode sites in Figure 5. The results of the PCA decomposition of the target-locked processing interval, which suggested the retention of three spatial and eleven temporal components is displayed in Figure 2 of the Supplementary Materials. Six of these spatiotemporal components could be identified as corresponding with conventional ERP components and were selected for further analysis. P1 and N1 are visible at approximately 100 and 190 ms respectively over posterior recording sites. P2, N2, and P3a are visible between 200 and 500 ms over fronto-central recording sites. Finally, a P3b component is visible between 400 and 800 ms over posterior recording sites. The amplitudes of each of these components for each of the experimental conditions and groups are displayed in Figure 6.

P1*/N1*/P2*/N2*/P3_a* There were no significant effects related to task or diagnostic conditions at these ERP components.

P3_b* Amplitudes in the posterior P3_b* component were smaller for participants with schizophrenia, $F(1, 38) = 5.62, p < .05, \eta^2 = 0.12$. Contrary to expectation, the main effect of Congruency only approached significance, $F(1, 38) = 3.39, p = .07, \eta^2 = 0.08$. Moreover, there was no evidence of a Congruency X Diagnosis interaction in the P3_b component.

Stimulus-locked LRP

The amplitudes and time-courses of the stimulus-locked LRP are presented in Figure 7. The expected differences in LRP morphology for incongruent compared with congruent stimuli were clearly visible in the waveforms for healthy comparison participants. However, LRP morphology was dramatically altered in participants with schizophrenia.

Peak Amplitude—Analysis of the stimulus-locked LRP amplitudes revealed a significant interaction between Congruency and Diagnosis, $F_c(1, 38) = 5.45, p < .05$, confirming the qualitative observations of the LRP waveforms.

Peak Latency—Despite large qualitative differences, suggesting a delayed peak latency in the incongruent compared with congruent condition, there were no significant differences in peak LRP latency across task conditions and diagnostic status using the corrected F statistic.

Onset Latency—There were no significant differences in LRP onset latency across task conditions and diagnostic status.

Response-locked LRP

The response-locked LRP did not appear to vary systematically across task conditions. There were no statistically significant effects of task conditions or diagnostic status in any of the response-locked LRP measures. LRP waveforms time-locked to the response are available in Figure 3 of the Supplementary Materials.

Discussion

A preserved ability of participants with schizophrenia to shift attentional set was indicated in the present study by the equivalence of switch costs in the two participant groups and by evidence for an intact, switch-sensitive P3b brain response to cues to switch attention. Together, these findings suggest that individuals with schizophrenia, like healthy comparison participants, benefited from the presentation of task cues. The benefits of anticipatory preparation for a task shift have been consistently reported in healthy participants, demonstrating that switch costs are reliably reduced when time is given to prepare for the switch (Arbuthnott & Frank, 2000; Fagot, 1995; Rogers & Monsell, 1995; Wylie & Allport, 2000). Moreover, Meiran and Daichman (2005) demonstrated that the probability of executing a currently relevant task, which is initially reduced on switch trials, is restored when participants are given the opportunity for task preparation. Thus, If participants with schizophrenia had been unable deploy a task-appropriate attentional set using the contextual information provided by the cue then reaction times should not only have been longer in general, but should also have been associated with increased switch costs and error rates. This was not the case.

This finding replicates and extends a previously reported finding of intact set switching in schizophrenia (Kieffaber et al., 2006), but is antithetical to the conventional view that schizophrenia is associated with an ubiquitous task switching/context-updating deficit (Barch et al., 2001; Cohen & Servan-Schreiber, 1992; Elliott, McKenna, Robbins, & Sahakian,

1998;Everett, Lavoie, Gagnon, & Gosselin, 2001;Smith et al., 1998). To reconcile this contradiction it is suggested that the construct of “task set” must include a distinction between attentional (sensory/perceptual) and intentional (response-delegation) processes. The present data, in addition to the findings of Kieffaber et al. (2006), suggest that those cognitive processes that support the attentional component of set switching may be preserved in schizophrenia.

This observation may have been obscured in previous research because the contributions of attentional and intentional cognitive processes were not independently considered. For example, context processing deficits have been demonstrated in both medicated and unmedicated patients with schizophrenia as well as in unaffected first-degree relatives of individuals with schizophrenia using an AX version of the Continuous Performance Test (AX-CPT) (MacDonald, Pogue-Geile, Johnson, & Carter, 2003;Servan-Schreiber, Cohen, & Steingard, 1996). The AX-CPT task requires participants to respond to Xs appearing in a stimulus sequence. The appropriate response to the X is governed by the context on each trial, which is conveyed by the stimulus that precedes the X. Participants are typically instructed to respond to A-X trials and to withhold their response when the preceding stimulus is a not an A (e.g. BX trials). Because the majority of the trials are of the A-X type, success in withholding the prepotent tendency to respond to the X on B-X trials is considered indicative of ones ability to update context. While there is no question that context (i.e. set) updating is needed to cope with the changing task context compelled by the A and B stimuli, the relevance of the X stimulus is constant across trials and what changes is how responses are delegated to the X stimulus. Thus, because of the intentional nature of the set switching that occurs in this task, the finding that participants with schizophrenia demonstrate impaired context processing compliments rather than contradicts the present findings. Because response mappings (i.e., intentional set) were consistent across all trials in the present study, it is argued that a set switching aptitude was revealed in individuals with schizophrenia.

Another important aspect of the present results is that attentional set switching aptitude in schizophrenia was demonstrated in the context of an attentional set maintenance deficit. This result replicated earlier research with the same task (Kieffaber et al., 2006) and is consistent with at least one previously reported finding with respect to the sparing and loss of attentional control in schizophrenia (Mathalon, Heinks, & Ford, 2004). This important differentiation also provides evidence that the present findings are not due to sample-specific characteristics or to experimental factors like task difficulty. Moreover, the notion that set switching and maintenance reflect unique psychological constructs was further demonstrated by additivity in the ANOVA for reaction times and a non-significant statistical relationship between the switch and congruency costs.

Support for the present conclusions was also provided by the ERP analysis. Because maintaining a consistent response mapping negated the preparation of response-delegation processes in anticipation of the task, the finding that participants with schizophrenia, like healthy comparison subjects, evidenced P3b brain potentials in response to task cues that were larger on switch than stay trials supports the notion that the physiological processes that support attentional set switching are preserved. The findings reported here motivate the re-conceptualization of set effects in schizophrenia in terms of more specific information processing mechanisms like attentional and intentional set. It is argued that the improved specificity permitted by the independent consideration of attentional and intentional processes will lead to the development of improved neuropsychological tasks as well as improved theoretical resolution regarding the nature of executive dysfunction in this population. Ultimately, the development of improved theoretical clarity regarding set effects in both clinical and non-clinical populations requires that existing psychological constructs, like “executive control”, be articulated in terms of such constituent information processing mechanisms.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Schematic of the attentional set switching task,

Figure 2.

(A) Mean response latencies within each condition and group. (B) Mean accuracy rates within each condition and group. HC = healthy comparison, SZ = schizophrenia, and bars reflect the standard error of the mean.

Figure 3.
Grand average cue-locked ERP waveforms for a subset of midline electrode sites.

Figure 4. Spatio-temporal PCA scores reflecting cue-locked ERP component magnitudes in each condition and group. HC = healthy comparison, SZ = schizophrenia.

Figure 5.
 Grand average target-locked ERP waveforms for a subset of midline electrode sites.

Figure 6.

Spatio-temporal PCA scores reflecting target-locked ERP component magnitudes in each condition and group. Bars reflect the standard error of the mean.

Figure 7. Stimulus-locked LRP time-course and corresponding plots of average peak amplitude, peak latency, and onset latency for each group and condition. SW = switch, ST = stay, CON = congruent, INCON = incongruent.