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Switch and maintenance of task set in schizophrenia

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Abstract

Task set maintenance and switching deficits are robust in schizophrenia. However, little is known about how these constructs are related to one another. The development of an improved understanding of set switching and maintenance deficits in schizophrenia requires that these constructs be explicated in terms of elementary cognitive processes rather than grouped into broad psychological concepts like executive functioning. A relevant dichotomy has been proposed in which sensory and perceptual ("attentional") processes are distinguished from decisional ("intentional") processes in task maintenance and switching; however, the contributions these processes make to performance deficits in schizophrenia is not known. In the present study, 30 participants with schizophrenia and 27 healthy comparisons completed a cued attentional set switching task. In addition to analyses of mean response times, the contributions of attentional and intentional processes to task performance were estimated using an ex-Gaussian distributional analysis. Schizophrenia was associated with a set maintenance deficit that was accounted for by an attentional, rather than intentional, dysfunction. Both groups showed significant switch costs that could be attributed to attentional processes, but there was no evidence for an attentional set switching deficit in schizophrenia. The findings suggest that set switching and set maintenance may reflect distinct cognitive deficits in schizophrenia and that they may be associated with unique information processing mechanisms.

Keywords: Executive control; Context; Cognitive control; Set-switching; Task-set; Schizophrenia

1. Introduction

Cognitive deficits are central to the characterization of schizophrenia in both early (Bleuler, 1950) and contemporary (Andreasen, 1999; Friston, 1999; Tononi and Edelman, 2000) conceptualizations of the disorder. A prominent theory that has been advanced regarding cognitive deficits in schizophrenia suggests that poor cognitive performance can be attributed to an ubiquitous inability to maintain and/or revise "set" (Allan, 1978; Cohen and Servan-Schreiber, 1992; Huston et al., 1937; Pantelis et al., 1999; Rosenbaum et al., 1997; Shakow, 1962; Zahn and Rosenthal, 1965). Also called "mental set" or "task set," the concept of set refers to a

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configuration of perceptual, cognitive, and response biases that serve to optimize task performance. It is widely accepted that the ability to maintain and adapt these optimal cognitive configurations is central to concepts like cognitive flexibility and executive control.

The argument for specific deficits of set maintenance and switching in schizophrenia is rooted in long-standing evidence that patients with schizophrenia do not improve their response time when the onset of a response-eliciting target stimulus is reliably cued and the cue–target delay is more than several seconds long (Huston et al., 1937). This failure to optimize responses has been attributed to the misallocation of cognitive resources during the cue–target interval (CTI) and has been cited as evidence of a failure to maintain an appropriate task set (Huston et al., 1937; Rodnick and Shakow, 1940). Moreover, the finding that performance deficits in schizophrenia are increased when the nature of the task set changes across trials led to the argument that the inability to modify a task set, or switch from one task set to another, is the aspect of attentional dysfunction that differentiates schizophrenia from other psychiatric and non-psychiatric groups (Zubin, 1975).

Task set switching refers to the realignment of perceptual, cognitive and motor goals in order to maximize processing efficiency on the currently relevant task. Characterized by shifts in task protocols, the Wisconsin Card Sorting Test (WCST) is frequently used to measure task set switching in clinical populations. An increased number of perseverative errors on the WCST is a common finding in participants with schizophrenia and is often interpreted as an inability to switch task set from a previous to a current sorting rule (Crider, 1997; Everett et al., 2001; Koren et al., 1998). In the non-clinical literature, set switching is commonly evaluated using task switching paradigms in which participants alternate between two (or more) tasks. When the tasks alternate, the first trial of the newly relevant task (a.k.a. switch trial) is typically associated with increased response time (RT) and decreased accuracy compared with trials on which the task is repeated (a.k.a., stay trials) (Allport et al., 1994; Fagot, 1995; Rogers and Monsell, 1995). The RT difference on switch and stay trials is commonly referred to as the "switch cost."

Unlike task set switching, which involves the modification of cognitive biases, task set maintenance refers to the ability to regulate the impingement of competing task sets on ongoing processing. Performance on the Stroop Color-Word Test (Smith et al., 1998) is commonly considered to index task set maintenance because it yields indices of interference and facilitation via performance on incongruent and congruent (relative to neutral) trials (Kane and Engle, 2003; Pollux and Robertson, 2002). Increased interference and facilitation are common findings in schizophrenia and are typically interpreted as a failure to maintain an appropriate task set amidst the processing of both relevant and irrelevant features of a bivalent stimulus (Barch et al., 1999; Henik et al., 2002; McNeely et al., 2003). Because the task switching paradigms commonly used in cognitive psychology include bivalent stimuli, they also yield measures of set maintenance via interference and/or facilitation effects. In fact, the ability of the task switching paradigm to supply concurrent indices of set switching and maintenance in the forms of both response time (RT) and accuracy make it ideal for use in the present study of cognitive dysfunction in people with schizophrenia.

In contemporary neuropsychological literature, an explicit distinction between task set maintenance and switching is rarely made. However, some have suggested that set switching and maintenance constitute distinct cognitive processes (Altmann and Gray, 2000; Fassbender et al., 2004) and that they may even be associated with unique developmental trajectories (Crone et al., 2004). Discerning the nature of the relationships between deficits associated with the constructs of set maintenance and switching in schizophrenia may thus lead to an improved understanding of cognitive dysfunction in this population. Progress in the development of this understanding, however, requires that broad cognitive constructs like set maintenance and switching be rigorously characterized in terms of elementary cognitive processes rather than receiving an unqualified designation. Some have even argued that the most important goal of modern research in schizophrenia is the identification of elementary cognitive processes (Andreasen, 2000; Carter and Neufeld, 1999; Neufeld and Williamson, 1996). Because traditional neuropsychological tasks like the WCST inherently require a broad range of cognitive abilities, they lack the specificity required to shoulder the development of contemporary theories that emphasize the role of elementary cognitive processes. For example, explanations for poor performance on WCST have included assertions that the task measures frontal lobe executive function (Berman et al., 1986), attentional switching (Braff et al., 1991; Everett et al., 2001), working memory (Goldman-Rakic, 1994), and sustained attention (Smith et al., 1998). Many tasks used in the field of cognitive psychology, however, accommodate a more parsimonious and explicit theoretical interpretation, support rigorous characterization of the involvement of elementary cognitive processes and are suitable for use with clinical populations (e.g., Carter and Neufeld, 1999; Neufeld and Williamson, 1996; Riefer et al., 2002; Thapar et al., 2003).

Despite the limitations of traditional neuropsychological tests, candidate elementary processes in set switching and maintenance can be derived from interpretations of neuropsychological test performance in individuals with schizophrenia. For example, poor performance on tasks like the WCST and Stroop has been attributed to failures to selectively process task relevant information, failures to inhibit the processing of task-irrelevant information, and failures to inhibit inappropriate response alternatives (Barch et al., 1999; Crider, 1997; Elliott et al., 1998; Everett et al., 2001; Henik et al., 2002). These interpretations can be reduced to two distinct cognitive processes. The first is a sensory/perceptual process that is responsible for the discriminative selection of task-relevant information. The second is a decisional process responsible for the configuration of task-appropriate stimulus–response (S–R) mappings that facilitate the decision making processes acting on selected information in the service of producing a response.

The significance of this simple dichotomy of information processing in task set switching and maintenance research is also evident in the non-clinical literature where a distinction is sometimes made between ‘attentional’ and ‘intentional’ set, both derived from the broader concept of task set. *Attentional* set is said to refer to the set of rules governing the selection of stimuli and/or stimulus dimensions, whereas *intentional* set refers to the set of rules governing the selection of motor responses (Rushworth et al., 2002). Although this distinction has not received much explicit consideration in the literature on task switching to date, the correspondence between attentional and intentional set and the aforementioned sensory/perceptual and decisional processes offered to account for set switching and maintenance performance clearly reinforces its importance and relevance. Taken together, questions about the role of attentional and intentional processes in task set maintenance and switching are representative of the ongoing debate over the nature of information processing deficits in schizophrenia and motivate the primary hypotheses of the present research.

Taking into consideration the broader discourse on cognitive dysfunction in schizophrenia, a preponderance of the literature advocates an *attentional* deficit, emphasizing sensory and perceptual encoding abnormalities. This is evident at the intersection of behavioral and psychophysiological research where perceptual impairments in people with schizophrenia have been linked with sensory processing deficits (Brown et al., 2002; Kim et al., 2005), deficits of object recognition (Doniger et al., 2001; Tek et al., 2002), decreased signal amplification in the magnocellular visual pathway (Butler et al., 2005), and disrupted cortico-cortical integration (Krishnan et al., 2005; Kwon et al., 1999; Winterer et al., 2000). Aberrant perceptual encoding has also been implicated in formal modeling of cognitive dysfunction in schizophrenia (Broga and Neufeld, 1981; Carter and Neufeld, 1999; Neufeld and Williamson, 1996). Moreover, the rigorous formalization of cognitive constructs, like perceptual encoding, provides additional specificity with respect to the source of the encoding deficit. For example, Neufeld and Williamson (1996) demonstrate that perceptual encoding deficits in schizophrenia can be attributed to an increased number of encoding subprocesses rather than a decreased attentional capacity.

Considering the conventional emphasis on sensory and perceptual processes as the basis for cognitive dysfunction in schizophrenia, a parsimonious approach to the integration of the proposed distinction between attentional and intentional processes with contemporary research involving the constructs of set switching and maintenance is to assert that deficits in the switching and maintenance of task set in schizophrenia can be attributed to aberrant attentional but not intentional information processing mechanisms. According to such a theoretical stance, set switching deficits in schizophrenia can be articulated as an impaired ability to modify sensory/perceptual biases in favor of task-relevant stimuli and/or stimulus features and set maintenance deficits can be articulated as an impaired ability to sustain optimal sensory/perceptual encoding processes, resulting in increased processing of irrelevant information.

In the current study, a cued task switching paradigm was used to determine the nature of *attentional* set switching and maintenance deficits in schizophrenia. The influence of *intentional* processes was limited by maintaining a constant decisional mapping across all trials within participants. Switching from one task to the next in conventional task switching paradigms includes both a change in the relevant perceptual dimension (i.e., attentional set switching) as well as a change in the relevant decisional mapping (i.e., intentional set switching). For example, if the stimulus set consists of paired combinations of letters and numbers, the set of response alternatives for the first task might be "odd" and "even" while the response alternatives for a second task might be "vowel" and "consonant" (Rogers and Monsell, 1995). In the present experiment, however, the decisional mapping (i.e., set of possible responses) was held constant across all tasks and trial types while the relevant perceptual dimension varied across tasks (see Method). Switch costs (i.e., reaction time differences between switch and repeat trials) were used to index set switching whereas congruency costs (i.e., reaction time difference between congruent and incongruent trials) were used to index set maintenance. Despite the fact that inferences about the role of attentional processes in task set switching are permitted by virtue of the fact that the influence of intentional processes was limited by the invariance of response alternatives across trials, execution of the task obviously requires a translation of the perceived target stimulus into an appropriate response (i.e., an intentional process). Furthermore, inferences with respect to task set maintenance are complicated by the fact that the data analysis requires that trials be grouped according to stimulus congruency, a property of the stimulus that varies with respect to the set of appropriate responses (i.e., an intentional process). Thus, an additional goal of the present research was to estimate the contributions of attentional and intentional processes to set maintenance and switching using quantitative proxies for these mechanisms derived from an ex-Gaussian distributional analysis of the response times.

The ex-Gaussian function is the result of the convolution of a Gaussian and exponential distribution and has been shown to yield close approximations to empirical RT distributions (Hohle, 1965; Ratcliff and Murdock, 1976). Fitting the ex-Gaussian function yields three parameter estimates, typically designated as mu, sigma, and tau (μ, σ, τ), that characterize the overall shape of the RT distribution. The μ parameter reflects the mean of the Gaussian component of the distribution. The σ parameter reflects the Gaussian standard deviation (i.e., symmetric variance). Finally, the τ parameter reflects both the mean and standard deviation of the exponential component, influencing the tail of the distribution. Although the ex-Gaussian function is not intended to serve as a model of the relevant cognitive machinery, its parameters are thought to reflect the respective products of at least two broad classes of sensory/perceptual and response-generating cognitive processes (Hohle, 1965). Specifically, τ has been interpreted to represent decision time whereas μ can be interpreted to reflect the remaining input/output processes such as sensory/perceptual integration (Dolan et al., 2002; Hohle, 1965; Spieler et al., 2000). The ex-Gaussian decomposition, therefore, makes it possible to define quantitative proxies for attentional (μ) and intentional (τ) cognitive processes, providing a complementary analytic strategy to the conventional RT analyses and yielding unique parameters for use in describing the experimental effects in terms of their impact on several aspects of the distribution of RTs rather than merely the central tendency.

The assertion that set switching and maintenance are discrete but related psychological constructs and that deficits in schizophrenia can be accounted for by a common attentional dysfunction led to the following three specific predictions regarding response times and two predictions regarding the ex-Gaussian analysis. The predictions regarding the response time data were as follows: (1) Because switch costs are reliably reduced in healthy participants when task cues (or predictability) permit the anticipation or preconfiguration of task-set (Arbuthnott and Frank, 2000; Fagot, 1995; Rogers and Monsell, 1995; Wylie and Allport, 2000), participants with schizophrenia were expected to exhibit larger switch costs (i.e., a Switch × Group interaction effect), reflecting a relative inability to utilize contextual information provided by the cue to reconfigure an appropriate attentional task-set. (2) Increased interference effects (i.e., a Congruency × Group interaction) were also expected, reflecting an inability to maintain an appropriate task-set when the irrelevant target features are incongruent with the relevant target features. (3) The assertion that attentional deficits can account for deficits in both set maintenance and switching also leads to the prediction that indices of set maintenance and switching will be positively associated with one another.

Although intentional processes were limited in the current task by keeping decisional mappings constant, such processes cannot be excluded entirely from any task requiring an overt response. Thus, the ex-Gaussian distributional analysis was used to derive indices of attentional and intentional processes in the present data, complementing and extending the standard analyses of mean response times. The predictions regarding the ex-Gaussian analysis were: (1) Switch costs and the set switching deficit in schizophrenia were expected to be accounted for by changes in the μ (attentional) rather than the τ (intentional) component of the RT distribution. (2) Similarly, congruency costs and set maintenance deficits in schizophrenia were expected to be accounted for by changes in μ rather than τ. No specific predictions are made with respect to the σ parameter in terms of the behavioral deficit in schizophrenia.

2. Method

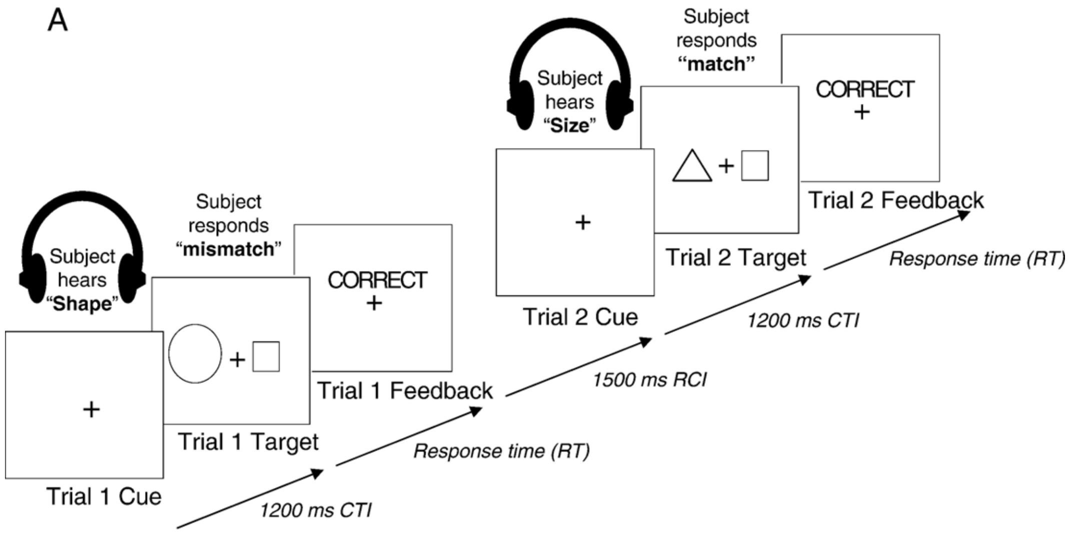
2.1. Participants

33 individuals meeting DSM-IV (American Psychiatric Association, 1994) criteria for schizophrenia and 30 healthy comparison participants were recruited and tested. Exclusion criteria included cardiovascular or neurological disease, history of a head injury resulting in loss of consciousness, meeting DSM-IV criteria for substance dependence within the 3 months prior to enrollment in the study, and meeting diagnostic criteria for current DSM-IV Axis I mood or anxiety disorder. All participants were between 18 and 65 years of age. Three participants from each group were removed from the analysis due to poor task performance as identified by accuracy rates more than 150% of the interquartile range below the first quartile. Thus, 27 (14 male: mean age = 41.9, S.D. = 12.9; 13 female: mean age = 36.5, S.D. = 12.1) non-psychiatric and 30 (22 male: mean age = 36.9, S.D. = 12.6; 8 female: mean age = 40.1, S.D. = 11.3) patients were included in the present study. Groups differed significantly with respect to educational attainment, $\chi^2(5) = 23.7$, $p < .001$, with the majority of patients (86%) having no education beyond high school and most of the healthy comparison sample (85%) having at least some college or advanced degrees. Importantly, however, Pearson's correlations computed within each participant group revealed that educational attainment was not significantly related to either RT or accuracy. Written informed consent was obtained from all participants.

Trained diagnosticians administered a clinical interview using the SCID-IP (First et al., 1996) and the Positive and Negative Syndrome Scale (PANSS) (Kay et al., 1987). Chart reviews were also conducted to acquire medication information and relevant history. Determination of DSM-IV schizophrenia subtype was possible for 23 of the participants with schizophrenia. Sixteen of those twenty-three participants were classified as paranoid based on conventional DSM-IV criteria, while seven were broadly classified as nonparanoid, having met criteria for either the undifferentiated or disorganized subtype. These subgroups (including participants with subtype unknown) did not differ with respect to age, sex, ethnicity, education, type of antipsychotic medication (i.e., typical vs. atypical) prescribed at the time of testing, or self-reported alcohol and nicotine use. The schizophrenia subgroups were also equivalent in terms of clinical symptomatology as assessed by the PANSS, which was available for 22 of the participants with schizophrenia (mean = 50.8; S.D. = 11.5). There were neither any group differences for any of the experimental performance measures nor were there any associations between performance and clinical symptoms. At the time of testing, 28 participants with schizophrenia were taking atypical antipsychotic medications, 1 was receiving a glutamate agonist, and 1 was receiving a study drug/placebo. Calculation of chlorpromazine equivalents was possible for 22 of the participants with schizophrenia (Davis, 1974; Woods, 2003). Chlorpromazine equivalent medication dosage did not correlate significantly with either mean RT or mean accuracy on the experimental task.

2.2. Procedure

A schematic of the task-switching paradigm is shown in Fig. 1A. The task required participants to judge paired combinations 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°]). The participant's task was to indicate, by left or right key press (standard QWERTY keyboard), whether the paired stimuli "matched" or "mismatched" according to a given rule. In the "shape" rule condition, stimuli matched if they were the same shape, regardless of their respective sizes. In the "size" condition, the pair of stimuli matched if they were the same size, regardless of their shapes. Response mappings were unchanged within-participants but were counterbalanced across participants. On each trial, the operative rule either changed ("switch" trial), thus requiring the participant to switch attentional set, or remained the same ("stay" trial). The operative rule was indicated by a spoken cue (i.e., "shape" or "size") presented 1200 ms before the onset of the target stimuli at 70 dB SPL. The duration for each of the cue stimuli was 365 ms. The to-be-discriminated visual stimuli were presented for 400 ms. A 3000-ms response window beginning at the onset of the target stimulus was provided; however, a response by the participant terminated the trial. Responses were immediately followed by visual feedback (i.e., "correct" or "wrong"), displayed for 500 ms. The subsequent trial began following a 1500 ms response–cue interval. In all, the paradigm consisted of 120 trials (60 per rule). Three different cue (i.e., task) sequences were used: a new task cue could appear after one ($N=30$), two ($N=15$), or four ($N=15$) consecutive trials of the previous rule (see Fig. 1B). In addition to yielding an experientially random sequence, the three staggered run lengths result in a trial sequence in which the global probability of a task switch was 0.5 and the local (conditional) probability of a task switch was also 0.5 on 75% of the trials (see



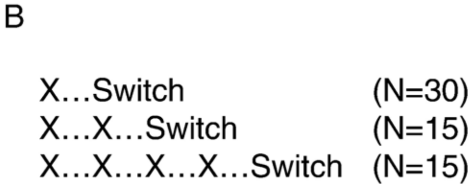


Fig. 1. (A) Procedural schematic demonstrating a task switch from the Shape to Size rule. Cue and target durations were 365 ms and 400 ms, respectively. (B) Schematic outline of the staggered run length design. Xs represent a complete trial (i.e., cue–target–response).

Kieffaber and Hetrick, 2005, for additional details). The local probability of a task switch on the remaining 25% of the trials was either zero or one (i.e., there were no task switches after three consecutive trials of a given rule and the absence of runs longer than four assured a task switch after four consecutive trials of a given rule).

A control task was administered prior to the task-switching task for all participants. Each trial of the control task proceeded identically to the experimental task with the exceptions that the target stimulus consisted of a single arrow presented to the center of the screen, pointing either right or left and the target stimulus was presented for 200 ms. The participant's task was simply to press the key on the side that corresponded to the direction of the arrow. The sequences of cues and arrows were orthogonal. The control task permitted the examination of simple target detection RT under similar experimental conditions.

2.3. Ex-Gaussian distributional analyses

Best fitting ex-Gaussian parameters were generated for each participant's observed distribution of RTs for the correct trials in each condition by minimizing the minus log likelihood function

$$\mathrm{Log}L(\theta) = -\sum_{i=l}^{N} \ln[f_{\mathrm{EXG}}(x_i;\mu,\sigma,\tau)] \qquad (1.1)$$

where ln is the natural logarithmic function, N is the number of observed RTs, and $f_{\mathrm{EXG}}(x_i)$ is the probability density of the ex-Gaussian distribution. The ex-Gaussian probability density function can be written as

$$f_{\mathrm{EXG}}(x) = \frac{1}{\tau}\left(\frac{\mu}{\tau} + \frac{\sigma^2}{2\tau^2} - \frac{x}{\tau}\right)\Phi\left(\frac{x-\mu\sigma^2/\tau}{\sigma}\right) \qquad (1.2)$$

where Φ represents the cumulative density of the Gaussian function. Computations, including the parameter search, were carried out using Matlab 6.1. None of the best-fitting ex-Gaussian parameters resulted in a significant chi square value, evaluated at $p<.05$ and $df=5$, indicating that the resulting parameters provided good fits to the empirical data.

Due to concern that the relatively small number of observations (30) in each of the four conditions might yield unstable estimates of the ex-Gaussian parameters, a Vincentizing procedure (Ratcliff, 1979) was used to evaluate the overall quality of the individual data fits.

Table 1
Mean (S.E.) and Vincentized parameter estimates across conditions in schizophrenia (SZ) and healthy control groups

	Group			
	HC	HCv	SZ	SZv
ConSW				
μ	877 (74)	838	1108 (70)	1087
σ	121 (25)	78	143 (24)	88
τ	343 (44)	365	503 (42)	497
InconSW				
μ	961 (91)	923	1335 (86)	1307
σ	167 (31)	111	205 (29)	156
τ	313 (48)	329	491 (46)	494
ConST				
μ	850 (74)	829	1083 (70)	1093
σ	149 (29)	133	153 (28)	144
τ	294 (44)	292	494 (42)	448
InconST				
μ	871 (89)	865	1244 (85)	1205
σ	137 (31)	108	172 (30)	134
τ	312 (46)	297	495 (44)	519

Vincentized parameter estimates are indicated by a lowercase v. (ConSW = Congruent switch trials, InconSW = incongruent switch trials, ConST = congruent stay trials, InconST = incongruent stay trials.)

Briefly, Vincentizing involves describing each participant's RT distribution in terms of quantiles and then aggregating those quantiles across participants. Best fitting parameter values were then obtained for the smoother, Vincentized data. The results for the individual participants and Vincentized data are displayed in Table 1. Each of the parameter estimates generated using the Vincentized data fell within the 95% confidence interval of the corresponding parameter estimate generated using individual participants data, supporting the validity of the parameter estimates obtained with the individual participant data. Each of the ex-Gaussian parameters, obtained by fitting individual's empirical RTs, was then submitted to separate Switch (2) × Congruency (2) × Group (2) ANOVAs.

3. Results

3.1. Accuracy and RT analyses

3.1.1. Control task

Performance on the control task was nearly perfect in both groups with healthy comparison participants (mean = .99; S.D. = .01) only slightly more accurate than participants with schizophrenia (mean = .98; S.D. = .06). Response latencies, however, were dramatically longer in participants with schizophrenia (mean = 1157.70; S.D. = 518.05) than in healthy comparison (mean = 717.81; S.D. = 331.49) participants, $F(1,55) = 14.21$, $p < .001$, $\eta^2 = 0.21$.

3.1.2. Experimental task: response accuracy

Generally speaking, performance on the attention switching task was very good; however, accuracy rates were lower in participants with schizophrenia (mean = 0.90; S.D. = 0.07) than healthy comparison (mean = 0.96; S.D. = 0.07) participants, $F(1,55) = 11.40$, $p < .001$, $\eta^2 = 0.17$. Response accuracies for each condition were entered into a mixed model ANOVA with Switch and Congruency as within-participant factors and Diagnosis as a between-participants factor. Switch costs were not evident in either group in the accuracy rates. Response congruency, however, impacted task performance with decreased accuracy rates in the incongruent (mean = 0.90; S.D. = 0.11) compared with the congruent (mean = 0.96; S.D. = 0.04) condition, $F(1,55) = 19.75$, $p < .001$, $\eta^2 = 0.24$. Moreover, the effect of congruency was significantly larger in participants with schizophrenia, evidenced by a Congruency × Diagnosis interaction, $F(1,55) = 8.94$, $p < .01$, $\eta^2 = 0.11$ (see Fig. 2B).

3.1.3. Experimental task: response latency

Correct-only RT data were submitted to an ANOVA equivalent to that used with the accuracy data. RTs were dramatically longer in participants with schizophrenia (mean = 1690; S.D. = 457) than in healthy comparison (mean = 1197; S.D. = 455) participants, $F(1,55) = 16.01$, $p < .001$, $\eta^2 = 0.23$. Switch trials were associated with significant switch costs, $F(1,55) = 19.83$, $p < .001$, $\eta^2 = 0.26$, with RTs to Switch (mean = 0.96; S.D. = 0.04) trials approximately 90 ms longer than Stay trials (mean = 0.96; S.D. = 0.04) in both schizophrenia and healthy comparison groups. Similar to the accuracy findings, RTs were associated with target congruency, $F(1,55) = 26.69$, $p < .001$, $\eta^2 = 0.29$, such that RTs were longer in response to incongruent stimuli. Moreover, this adverse effect of incongruency was significantly larger in the participants with schizophrenia, $F(1,55) = 10.16$, $p < .01$, $\eta^2 = 0.11$ (see Fig. 2A). Finally, using switch and

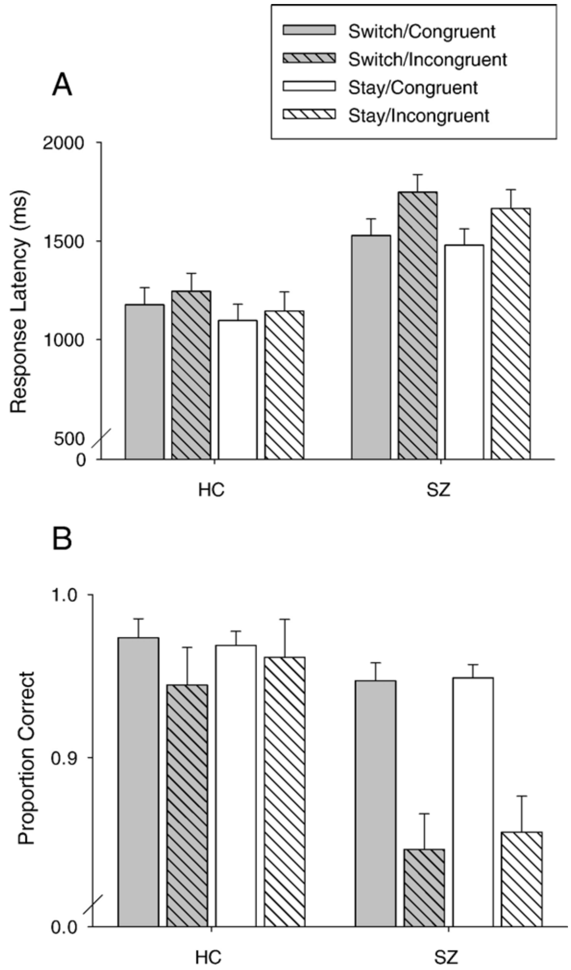


Fig. 2. (A) Mean response latencies across conditions for schizophrenia (SZ) and healthy comparison (HC) groups. Error bars reflect the standard error of the mean. (B) Mean accuracy rates across conditions and groups. Error bars reflect the standard error of the mean.

congruency costs as indices of set switching and maintenance respectively, switching and maintenance were found to be unrelated to one another in both schizophrenia, $r(30) = .101$, $p = \mathrm{NS}$, and healthy comparison, $r(27) = .176$, $p = \mathrm{NS}$, groups.

3.2. Ex-Gaussian analyses

3.2.1. Attentional set (μ)

Analysis of the μ (see Fig. 3A) parameter, reflecting the mean of the Gaussian component of the distribution and indexing attentional processes,

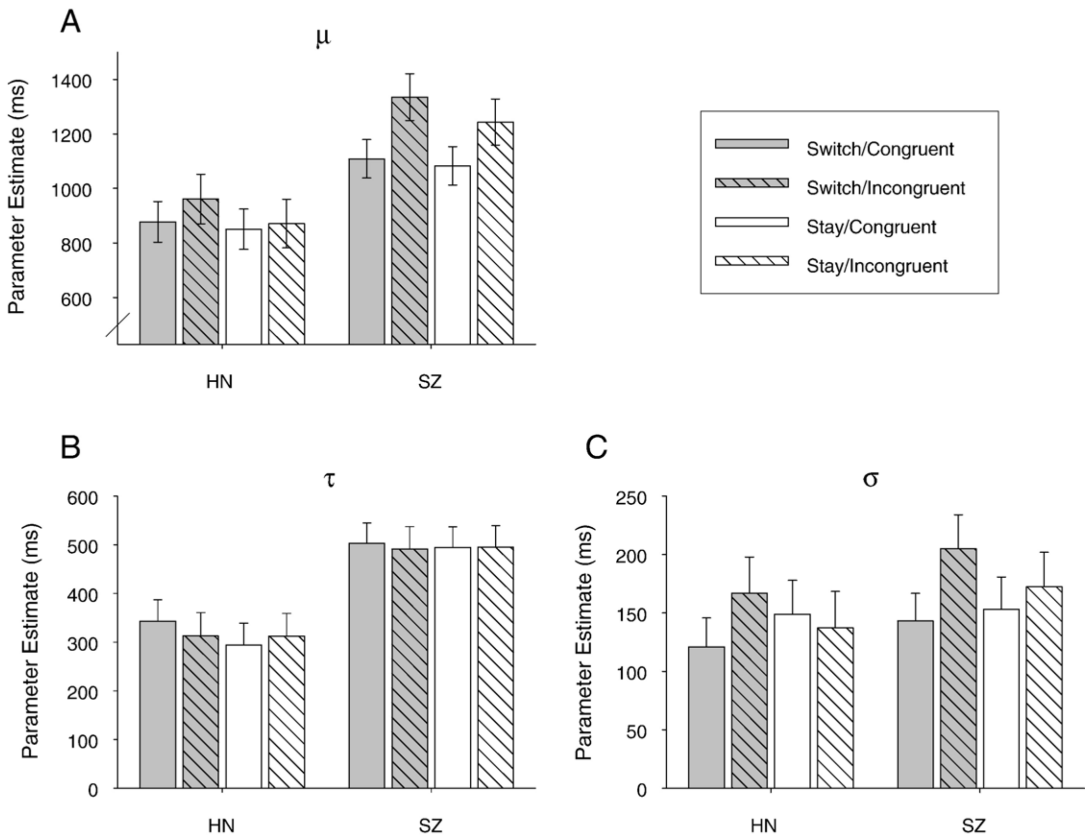


Fig. 3. Mean value of best fitting estimates for (A) μ, reflecting attentional processes, (B) τ, reflecting intentional processes, and (C) σ parameters. Error bars reflect the standard error of the mean.

indicated that the overall increase in RTs in the participants with schizophrenia could be accounted for by a shift in the Gaussian component of the RT distribution, $F(1,55)=8.21$, $p<.01$, $\eta^2=0.13$. Switch trials were associated with a significant increase in μ, $F(1,55)=7.29$, $p<.01$, $\eta^2=0.12$, but there was no Switch × Diagnosis interaction. A main effect of Congruency was also evident in μ, $F(1,55)=16.67$, $p<.001$, $\eta^2=0.22$, wherein incongruent stimuli were associated with an increase in the μ component of the response time distributions. The Congruency × Diagnosis interaction, evident in the RT analysis, was also present in the μ parameter, $F(1,55)=5.49$, $p<.05$, $\eta^2=0.07$.

3.2.2. Intentional set (τ)

Analysis of the τ (see Fig. 3B) parameter, reflecting the mean and standard deviation of the exponential component and indexing intentional processes, revealed that this component of the RT distribution was largely insensitive to the present experimental manipulations. This suggests that the contribution of intentional processes to the current task was consistent across trial types. However, group differences in τ indicated that an increase in the tail of their RT distributions, $F(1,55)=14.63$, $p<.001$, $\eta^2=0.21$, may have contributed to the overall increase in mean RT in participants with schizophrenia.

3.2.3. Symmetric variance (σ)

Analysis of σ (see Fig. 3C), showed a significant interaction between the Switch and Congruency conditions, $F(1,55)=4.08$, $p<.05$, $\eta^2=0.07$, suggesting that the increase in the symmetric variance of response times in Incongruent relative to Congruent conditions was larger in the Switch than Stay conditions.

4. Discussion

The present results support several conclusions regarding attentional set switching and maintenance in schizophrenia. First, schizophrenia was associated with a set maintenance deficit indicated by increased RT and error rates when responding to incongruent stimuli (e.g. a Stroop-like interference effect). Second, the set maintenance deficit in participants with schizophrenia could be accounted for by aberrant attentional (μ) rather than intentional (τ) processes. Third, indices of set switching and maintenance were uncorrelated in both schizophrenia and healthy comparison groups. Finally, schizophrenia was not associated with an attentional set switching deficit (i.e., switch costs were equivalent in schizophrenia and healthy comparison groups). The concurrent absence of attentional set switching deficits in schizophrenia and the marginalization of intentional processes in the current task (i.e., maintaining decisional consistency and response meanings across all trials) raises the possibility that intentional processes may play an important role in previously documented set switching deficits in people with schizophrenia.

An intact ability of participants with schizophrenia to switch attentional set was indicated in the present study by the equivalence of switch costs in the two participant groups. This equivalence is important because it suggests that all participants similarly exploited the opportunity to prepare following the task cues and that the impact of switching task set on response latency was equally detrimental to performance in participants with schizophrenia as in healthy comparison participants. The benefits of preparatory cues in task switching have been consistently reported in healthy participants, demonstrating that switch costs are reliably reduced when time is given to prepare for the switch (Arbuthnott and Frank, 2000; Fagot, 1995; Rogers and Monsell, 1995; Wylie and Allport, 2000). In other words, allowing time to prepare a task set leads to greater reductions in RT on Switch than Stay trials (i.e., reduced switch costs) when the ability to deploy and switch attentional sets is intact. Given that ample preparation time was provided in the present study (1200 ms) and, contrary to our predictions, switch costs were no larger in participants with schizophrenia than in the healthy comparison group, it is concluded that participants with schizophrenia were capable of deploying and switching attentional set in the context of the current task.

Despite the equivalency of switch costs in schizophrenia and healthy comparison groups, mean response times were approximately 500 ms longer in participants with schizophrenia. This prolonged response latency is consistent with the notion that schizophrenia is associated with a generalized failure to deploy attentional sets, however, such an explanation is contradicted by the equivalence of switch costs between healthy comparison and schizophrenia groups for the reasons stated above. Moreover, Neufeld and Williamson (1996) offer an interpretation of cognitive dysfunction in schizophrenia that may account for both the overall prolongation of RT in schizophrenia and the additivity of this RT increase across switch and stay trials. Their conception is that performance deficits in schizophrenia are due to perceptual encoding deficits; specifically, a “delayed latency for encoding-process completion” (p. 215). This argument is reinforced by a formal mathematical model characterizing the distribution of encoding completion times, suggesting that cognitive performance in people with schizophrenia is negatively impacted by the presence of surfeit cognitive subprocesses rather than a limited attentional capacity. Importantly, Neufeld and Williamson (1996) demonstrate that their interpretation can account for mean additivity of RT across increases in encoding load. Considering both previous research demonstrating that switch costs may reflect increased cue encoding demands on switch trials (Schneider and Logan, 2005) and the present evidence that switch costs are accounted for by changes in perceptual/encoding processes reflected in the attentional component of the ex-Gaussian analysis, the account proffered by Neufeld and Williamson (1996) appears to provide a parsimonious explanation for the present findings. Moreover, performance by participants with schizophrenia on the arguably simpler control task also manifested the 500 ms increase in response times, providing additional support to this interpretation.

Although the above explanation can account for the observed increase and additivity in RT and the μ parameter of the ex-Gaussian, it does not explain the overall increase in τ in participants with schizophrenia. The finding that τ was invariant across trial types validates the claim that intentional processes were controlled in the current paradigm. However, the significantly larger values of τ in participants with schizophrenia suggest that intentional processes may also contribute to the prolonged response latency in this group.

The conclusion that participants with schizophrenia may be unimpaired (relative to healthy comparison participants) in their ability to switch between attentional sets in anticipation of a target stimulus stands in contrast with the neuropsychological evidence that schizophrenia is associated with deficits in set switching (Elliott et al., 1998; Everett et al., 2001; Smith et al., 1998) and with evidence that individuals with schizophrenia are unable to implement task context (Barch et al., 2001; Cohen and Servan-Schreiber, 1992). Although one must consider the possibility that this contradictory finding may be related to sample-specific variability, the circumstances of the present investigation also raise important questions about the possible role of intentional processes in these varied set switching tasks. Because conventional neuropsychological tests confound changes in relevant perceptual dimensions (attentional switching) and decisional response mappings (intentional switching), one possible reconciliation is that previously reported set switching deficits be attributed to failures of intentional cognitive processes. Thus, set switching deficits were undetectable in the current paradigm because response mappings were consistent across all trials (within participants), limiting the role of intentional processing. Naturally, this interpretation requires both replications of the current findings as well as further research to address specific hypotheses regarding intentional set switching. However, the finding that participants with schizophrenia were proficient at switching task sets is consistent with at least one previously reported finding in which participants with schizophrenia were unimpaired in their ability to prepare a task set (Meiran et al., 2000). Moreover, Meiran and colleagues (2000) demonstrated that task switching deficits similar to those found in individuals with schizophrenia could be elicited in healthy comparison participants by manipulating response-mapping parameters consistent with intentional processes.

Whereas participants with schizophrenia were adept at switching attentional sets, the presence of incongruent information in the target display impacted task performance to a much greater extent in participants with schizophrenia compared to healthy comparison participants. This Stroop-like interference effect has been well documented in both healthy and schizophrenic populations (Henik and Salo, 2004; Jensen and Rohwer, 1966) and is typically attributed to failures of "selective attention" wherein task-irrelevant information impinges on ongoing processing (Cohen and Servan-Schreiber, 1992). Such an interpretation was confirmed by the finding that congruency effects were related to changes in the μ component of the ex-Gaussian distribution, indicating that the integration/encoding of stimulus information was delayed on incongruent trials. Whereas the encoding delays imposed by task switches were equivalent in the schizophrenia and healthy comparison groups, the impact on attentional processes by stimulus incongruency was much larger in participants with schizophrenia (indicating the set maintenance deficit). Importantly, this finding is consistent with the present hypotheses and with a wide body of literature indicating general deficits in the fluid processing of perceptual information in schizophrenia (Brown et al., 2002; Butler et al., 2005; Doniger et al., 2001; Kim et al., 2005; Krishnan et al., 2005; Kwon et al., 1999; Tek et al., 2002).

The ex-Gaussian analysis permitted further characterization of set maintenance and switching in terms of elementary cognitive processes. However, the results of this analysis lead to some conclusions that contradicted the original hypotheses. For example, it has been concluded that measures of set maintenance are theoretically distinct from set switching and that they are differentially associated with attentional and intentional cognitive processes. Although this conclusion is reconcilable with the findings that the effects of valid vs. invalid task preparation are independent of the effects of stimulus-evoked competition (Hübner et al., 2003), two immediate corollaries of the present conclusions were also tested. First, the magnitude of an individual's RT switch cost should be more closely related to differences in τ than in μ. Second, RT maintenance costs should be more closely related to differences in μ than in τ. Recall that the ex-Gaussian analysis permits a representation of the distribution of RTs in each of the experimental conditions in terms of both μ and τ. Thus, analogous switch and maintenance costs can be determined for each of the μ and τ parameters, making it possible to test the two corollaries of the present conclusions. An exploratory analysis was conducted to determine the correlations between conventional RT switch and maintenance costs and their parameter-based analogues (i.e., μ-switch, μ-maintenance, τ-switch, and τ-maintenance). Validating the present conclusions, RT maintenance costs correlated significantly with μ-maintenance costs, $r(57)=.697$, $p<.001$, but not τ-maintenance costs, and RT switch costs correlated significantly with τ-switch costs, $r(57)=.394$, $p<.01$, but not μ-switch costs. This finding provides additional support for the present distinction between attentional and intentional processing and promotes the conclusion that set switching and set maintenance deficits may also be associated with distinct elementary processes.

The present results suggest that task set maintenance and switching can be better understood in terms of an information processing dichotomy that distinguishes between attentional and intentional cognitive processes. Furthermore, it is suggested that deficits in task set maintenance and switching may be distinguished in terms of these two categories of cognitive processes. The improved specificity permitted by the independent consideration of attentional and intentional mechanisms can lead to an improved ability to characterize the nature of cognitive deficits in schizophrenia and to differentiate between psychiatric populations. Moreover, through the development and testing of formal computational models of these specific mechanisms, a functional mapping can eventually be determined between broadly defined psychological constructs and elementary cognitive processes. Together, the identification of specific indices of cognitive dysfunction and the resolution of a functional mapping that describes how those indices contribute to the observed behavior in terms of information processing mechanisms, will strengthen theoretical resolution regarding the nature of attentional deficits in schizophrenia, promote a more accurate characterization of the schizophrenic phenotype, and ultimately lead to an improved understanding of the etiology of the disorder.

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