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Task Set Switching in Schizophrenia

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The authors used a task-switching paradigm to investigate set shifting ability in schizophrenia. This paradigm included 2 choice reaction time (RT) tasks: up–down and right–left. Switching tasks were associated with costs (i.e., longer RT in task-switch trials than in task-repetition trials); patients responded more slowly than controls and suffered greater switching costs, were as efficient as controls in engaging in an upcoming task set, and were faster than controls in disengaging from the previous task set. There were indications that patients quickly forgot what each keypress indicated, making it necessary for them to acquire response meaning information anew in each trial. To test this notion, the authors subsequently tested normal participants in conditions in which response meaning information needed to be acquired anew in each trial. These participants produced a pattern of switching costs resembling that of patients. Results suggest that set switching difficulties in schizophrenia, as exhibited in the present paradigm, reflect poor memory for task context information.

Schizophrenia is a psychiatric condition associated with marked changes in cognitive functioning (Frith, 1992). This includes IQ (Frith, Leary, Cahill, & Johnstone, 1991; Nelson et al., 1990; Payne, 1973), language (Faber, Abrams, & Taylor, 1983; Faber & Reichstein, 1981), control of semantic processing (e.g., Henik, Nissimov, Priel, & Umansky, 1995), attention (e.g., Gjerde, 1983), and memory (e.g., McKenna, 1987). A major impairment is in executive functions (Goldberg, Weinberger, Berman, Pliskin, & Podd, 1987; Shallice, Burgess, & Frith, 1991), including set shifting ability. Aside from the neuropsychological implications, set shifting ability is highly relevant for everyday functioning, in which task demands and contexts change rapidly.

Indirect evidence for poor set shifting ability in schizophrenia comes from a variety of tests. These include the Trail Making Test Part B (e.g., Gold, Carpenter, Randolph, Goldberg, & Weinberger, 1997), where switching between numbers and the alphabet is required. Also relevant is the increased modality shift effect among schizophrenia patients (R. Cohen & Rist, 1992; Rist & Cohen, 1991). The modality shift effect is observed when the stimulus modality in simple reaction time (RT) changes.

Many studies have examined performance on the Wisconsin Card Sorting Test (WCST; Heaton, 1981; e.g., Fey, 1951; Liddle & Morris, 1991; Morice, 1990; Van Der Does & Van Der Bosch, 1992, for review). The WCST requires participants to identify a sorting rule (e.g., color) on the basis of feedback. After the participant has learned a sorting rule, the rule is changed without announcement, and the participant needs to identify the new rule. Studies on the WCST have demonstrated that schizophrenia is associated with an increased number of perseverative errors, responses that would have been considered correct according to the previously relevant sorting rule. Elliot, McKenna, Robbins, and Sahakian (1995, 1998) used a variant of the WCST, the Extra Dimensional Shift Test. The test requires participants to select one of two figures, which differ along two dimensions (e.g., shape and line). Their choice indicates what they believe to be the relevant dimension. As in the WCST, participants learn the rule on the basis of feedback. After having learned the rule, the rule is changed. Of interest are two rule transitions. In the "learned irrelevance" transition, a stimulus dimension that has been previously ignored becomes the relevant dimension, and a new irrelevant dimension is introduced. In the "perseveration" transition, the previously relevant dimension becomes irrelevant, and a new relevant dimension is introduced. Elliot et al. (1995, 1998) found that schizophrenia patients showed impairment in the perseveration transition but not in the learned irrelevance transition. One problem is that perseverative errors on the WCST, which constitute the evidence for set shifting

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difficulties, may reflect impairment in a variety of other abilities. These include the ability to abstract rules, benefit from feedback, and keep track of past choices (Goldman, Axelrod, Tandon, & Bernet, 1991).

In recent years, there has been an effort to design tasks that isolate set shifting abilities while minimally tapping other abilities. One such paradigm is task switching, in which participants rapidly switch between RT tasks that are typically performed on the same set of stimuli (e.g., switching between color discrimination to shape discrimination performed on shapes in different colors). In this paradigm, the most important performance index is task-switching cost, indicated by poorer performance in the switch condition relative to the no-switch condition (e.g., Allport, Styles, & Hsieh, 1994; Jersild, 1927; Meiran, 1996; Rogers & Monsell, 1995). Unlike in the WCST, the tasks in this paradigm require minimal abstraction abilities, and normal participants often perform them easily, with perfect accuracy. Moreover, feedback is not essential for successful performance, and there is no need to keep track of previous choices or to identify a rule. In other words, the task-switching paradigm presumably measures only a subset of the abilities involved in the WCST.

The paradigm we used was similar to that studied by Meiran (1996). In his experiments, participants were required to indicate the location of a target stimulus (smiling face) within a 2 × 2 grid (see Figure 1). Two tasks were ordered randomly. One task involved up versus down discrimination (ignoring the horizontal dimension), whereas the other task involved right versus left discrimination (ignoring the vertical dimension). Each trial began with an empty grid for fixation, followed by an instructional cue indicating which task to perform, up–down or right–left. Then, a target stimulus was presented. Responses were followed immediately by the next trial (fixation–cue–target). Switch trials were trials preceded by a different task, for example, a trial involving the up–down task, preceded by a trial involving the right–left task. No-switch trials were those in which the task was the same as in the previous trial. It is important to note that the cue was presented before the target, giving the participant the opportunity to prepare for the task. The interval between the cue and presentation of the target, the cue–target interval, was varied to induce different degrees of preparation. Previous studies on normal young adults have demonstrated that increasing the cue–target interval resulted in a marked reduction in switching costs (e.g., Meiran, 1996, in press-a, in press-b; Meiran, Chorev, & Sapir, in press).

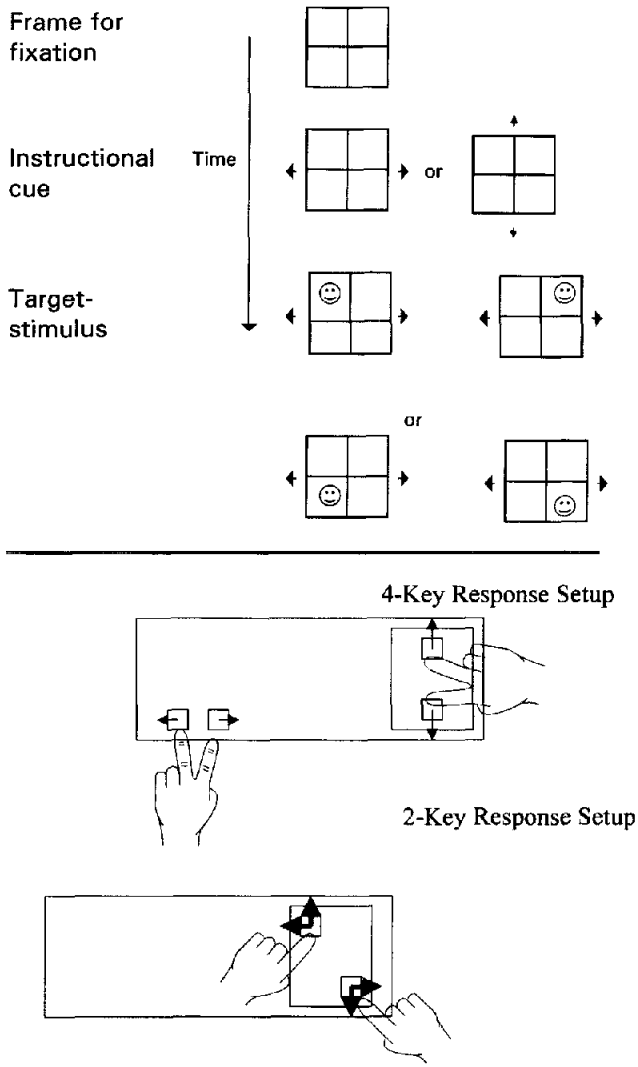

Figure 1. The experimental paradigm. The four-key setup is the one used in Experiments 1 and 2 and by Group 1 in Experiment 3. The two-key setup was used in Experiment 3 by Group 2. Half of the participants responded in the way depicted in the figure, and the other half used the upper right key to indicate up and right and the lower left key to indicate down and left.

General Method

Apparatus and Stimuli

We used an IBM clone for testing, with software written in MEL 1.0 (Schneider, 1988). The stimuli were the same as those used by Meiran (1996, Experiments 2–4). They were drawn in white on a black background with the graphic symbols found in the extended ASCII code. The smiling face character (ASCII Code 1), which subtended approximately 0.3° (width) × 0.5° (height), was the target stimulus (visual angles were computed assuming that participants sat approximately 60 cm away from the computer monitor). The arrow heads (ASCII Codes 16, 17, 30, and 31) subtended approximately 0.3° × 0.3° and were positioned 0.7° from the end of the grid. The grid subtended approximately 3.4° (width) × 2.9° (height). Participants responded by pressing keys on the keypad (see Figure 1), which were marked by arrows to indicate their meaning. RT was measured by the software to the nearest 1 ms.

Procedure

Each experiment involved a single session of RT testing. All patients underwent an interview to determine their diagnosis according to the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; *DSM–IV*; American Psychiatric Association,

1990). Patients who successfully completed the RT testing also underwent a second interview intended to assess symptoms according to the Positive and Negative Syndrome Scale (PANSS; Key, Opler, & Fiszbein, 1987). The diagnostic interviews were conducted by an experienced psychiatrist within 48 hr of the RT testing.

RT testing. The instructions were presented on the computer screen and were explained verbally. There was a warm-up block of 20 trials, followed by four blocks of 96 trials each (Experiments 1 and 2) or 128 trials (Experiment 3). A trial consisted of the following events: (a) an empty grid for fixation during the response–cue interval, (b) the instructional cue that remained visible throughout the target presentation, and (c) the target stimulus that was presented until the response. In Experiment 1, there were 32 possible trial combinations produced by crossing target position (4), task switch (2), and cue–target interval (4). In Experiments 2 and 3, there were eight combinations produced by crossing target position and task switch. Each experimental block consisted of 3 (Experiment 1), 12 (Experiment 2), or 16 (Experiment 3) repetitions of all possible combinations, randomly rearranged for each presentation. Before the statistical analysis, we collapsed data across target position so that each experimental condition was presented 48 times in the course of Experiments 1 and 2, and 64 times in Experiment 3.

PANSS. The PANSS consists of rating scales to evaluate symptom severity from 1 (*absent*) to 7 (*extreme*). We computed three composite scores. The positive symptoms score was composed of seven symptoms, including delusions and conceptual disorganization. The negative symptoms score was composed of seven symptoms, including blunted affect, emotional withdrawal, and poor rapport. Finally, the general symptoms score was composed of 16 symptoms, including somatic concern, anxiety, and guilt feelings.

Participants (Experiments 1 and 2)

Patients. The patients had been hospitalized for extended periods of time in the Beer-Sheva Mental Health Center, Beer-Sheva, Israel and had received medication for more than 3 years. We tested patients who were judged to be able to complete the tasks and comprehend the instructions. This was evaluated by the treating psychiatrist and members of the hospital staff who worked in the same ward. A few patients suffered from Parkinsonian side effects in the past, and these patients were treated with Cogentin. None of the patients suffered from these side effects during the study. The most frequently prescribed medications used to treat the patients included haloperidol, perphenazine, and chlorpromazine, with a few patients treated with clozapine. None of the patients had any significant change in their clinical condition within the period of the study, as judged by the treating psychiatrist. Patients were recruited if their current diagnosis according to *DSM–IV* criteria was schizophrenia, with a 3-year minimal duration of the disease, and no other psychiatric comorbidity in *DSM–IV* Axis I. Patients were excluded from the study if they suffered from eating or sleep disorders, had serious suicidal thoughts, confusion due to intense psychotic thoughts, impairments in orientation, severe anxiety, a history of other *DSM–IV* Axis I diagnoses, physical disorder demanding present drug therapy, pregnancy in women, current or past neurological disorder, receiving treatment other than psychotropic medications, change of psychotropic medications 4 weeks prior to the study, alcohol or substance abuse, or receiving electroconvulsive treatment in the year prior to the study.

Thirteen patients participated in both Experiments 1 and 2, and 14 (7 in each experiment) took part in one experiment only. Eleven participants did not complete Experiment 1, 10 of them were not recruited in Experiment 2, and 1 was recruited and succeeded. Three additional patients did not complete Experiment 2. Out of 40 patients tested, 13 did not complete the task. According to an informal observation, patients failed for various reasons: Five patients failed because of an inability to persist and lack of energy, and 3 were delusional or were hallucinating (i.e., thought that the grid expanded and shrank, or thought that all the targets were located in the center of the grid). Most failed because of comprehension problems. These included not being able to tell right from left and up from down, inability to relate the instructional cues to the display, or inability to remember what each keypress indicated. (It is important to note that a given patient may have exhibited several problems.) Even among the patients who succeeded, some had persistence problems or needed to be reminded what each response meant. Table 1 presents the demographic details of the patients who completed the study and the control participants. Also included are drug dosages (in terms of chlorpromazine equivalent; Kaplan & Sadok, 1991) and PANSS summary scores. Patients were paid 4 NIS ($1.00) per session, and additional 10 NIS (approximately $2.50) were contributed to the department.

Control participants. Controls were recruited from hospital staff and maintenance personnel at Ben Gurion University of the Negev, Beer-Sheva, Israel. They were within the same range of ages and years of education as the patients and reported no history of neurological disease, psychiatric disease, or alcohol–substance abuse. Fourteen persons participated in both experiments, and the remaining 12 participants were tested in one experiment only. Control participants were paid 14 NIS ($3.50) per session. All the control participants completed the task successfully.

Analytic Procedure

The first response in each block, responses that were preceded by errors, and responses that were preceded by exceedingly long RTs (6 s) were excluded from all the analyses. The reason being that in all of these instances, we could not be sure that the participant had fully adopted the required set in the previous trial. In the remaining responses, if RT was longer than 6 s, the response was analyzed for accuracy only. Given the fact the RT distributions were skewed, we represented each condition by the harmonic mean, which is based on the inverse transformation, 1/RT, as recommended by Ratcliff (1993) to improve statistical power.

Experiment 1

The purpose of the present experiments was to examine whether switching costs are increased in schizophrenia. The relevant index is the two-way interaction between the task switch (switch vs. no-switch) and group (patients vs. controls). In Experiment 1, we examined whether the ability to prepare for a task switch is compromised in schizophrenia. This ability is indicated by the rate of reduction in switching costs as a function of preparation time (cue–target interval), with a faster rate indicating better preparation. This effect indicates the engagement in the set of the upcoming task. A compromised task-set engagement ability would be indicated by a significant triple interaction between group, task switch, and cue–target interval. The four-key response setup (Figure 1) was used in Experiments 1 and 2.

Method

Participants. There were more men than women in the patient group, and the reverse was true for the control group; this differ-

Table 1
Description of the Participants Who Completed Experiments 1 and 2

Measure	Experiment 1		Experiment 2	
	Patients	Controls	Patients	Controls
Sex (male/female)	14/6	12/8	12/8	8/12
Age (years)				
M	39.9	38.6	42.0	42.3
SD	9.9	9.1	9.5	8.8
Education (years)				
M	10.6	11.3	10.0	10.8
SD	2.2	1.4	2.9	0.8
Drug dosage (chlorpromazine equivalent)				
M	515.0		506.3	
SD	491.9		401.5	
Positive symptoms (1–7)				
M	2.84		2.79	
SD	0.72		0.69	
Negative symptoms (1–7)				
M	3.06		2.96	
SD	1.09		0.78	
General symptoms (1–7)				
M	2.11		2.14	
SD	0.45		0.49	

ence did not approach statistical significance ($p = .11$, Fisher's exact test). Nonetheless, this tendency in the distribution could have introduced various artifacts. To rule out this possibility, we analyzed RT with sex as an additional independent variable, and neither its main effect nor its interactions with the other independent variables were significant. As can be seen in Table 1, the groups were almost identical with respect to mean age and mean years of education, and a series of *t* tests supported this impression by indicating nonsignificant group differences.

Procedure. In the present experiment, the response–cue interval was fixed at 1,532 ms. Previous studies on normal young adults indicated that switching costs are barely influenced by response–cue interval when that interval exceeds 1 s (Meiran et al., in press). The cue–target interval varied randomly within blocks of trials (132, 432, 1,032, or 3,032 ms).

Results

The mean of harmonic means (of correct responses) and proportion of errors are presented in Table 2.

RT. The results indicate that the patients responded more slowly and suffered larger switching costs than the control participants did. There was evidence for effective task preparation in both groups, indicated by a reduction in switching costs because of increasing preparation time. In fact, task preparation was more effective among the patients than among the control participants.

These conclusions were supported by a mixed model 2 × 2 × 4 analysis of variance (ANOVA), in which the independent variables were group (schizophrenia patients, controls) as a between-participants effect, and task switch (switch, no-switch) and cue–target interval (132, 432, 1,032, and 3,032 ms) as within-participants effects. There were significant main effects of group, $F(1, 38) = 38.16$, $p < .0001$; task switch, $F(1, 38) = 74.71$, $p < .0001$; and cue–target interval, $F(3, 114) = 34.94$, $p < .0001$. In addition, there was a significant two-way interaction between task switch and group, $F(1, 38) = 9.77$, $p < .005$, and between cue–target interval and task switch, $F(3, 114) = 12.93$, $p < .0001$. The triple interaction was just significant, $F(3, 114) = 2.68$, $p = .05$. The triple interaction is depicted in Figure 2. As can be seen, the group difference in switching costs was exceptionally large when cue–target interval was shortest.

The schizophrenia patients exhibited slow responses relative to normal controls, as commonly found (e.g., Rist & Cohen, 1991). It could be argued that the increased switching costs among the patients were due to general slowing. To test this notion, we applied a Brinley plot analysis, in which the means of the patients are plotted as a function of the equivalent means in the control group. A linear function with a slope greater than 1 would support the notion of general slowing. The Brinley plot is presented in Figure 3.

A linear regression analysis indicated that .83 of the patient group mean RT could be predicted on the basis of the equivalent control group mean. One mean was outside the 95% confidence interval (marked by an arrow), and it corresponded to the no-switch condition at the shortest cue–target interval. This mean was considerably shorter than would be predicted by general slowing. In other words, the relatively large task-switching cost in the shortest cue–target interval, which had caused the just-significant triple interaction, could not be explained by general slowing. However, in all other cases, the increased switching cost could be explained by general slowing. Another way to examine this issue it to examine proportional costs (see Table 1), in which switching cost is divided by no-switch RT. Proportional costs were remarkably similar in the two groups, except for the shortest cue–target interval.

Error rate. We analyzed the proportion of errors results using an ANOVA with the same independent variables as in the analysis of RTs. There were significant main effects of

Table 2
Mean Reaction Time (RT) and Proportion of Errors (PE) for Experiment 1

Cue–target interval	Switch	No-switch	Cost	Proportional cost
		Patients		
132 ms				
RT	2,139	1,651	488	.30
PE	.09	.03	.06	
432 ms				
RT	1,888	1,635	253	.15
PE	.07	.02	.05	
1,032 ms				
RT	1,823	1,617	206	.13
PE	.05	.02	.03	
3,032 ms				
RT	1,703	1,598	105	.07
PE	.05	.03	.02	
		Controls		
132 ms				
RT	1,145	941	204	.22
PE	.04	.01	.03	
432 ms				
RT	945	814	131	.16
PE	.02	.00	.02	
1,032 ms				
RT	884	787	97	.12
PE	.01	.01	.00	
3,032 ms				
RT	862	801	61	.08
PE	.01	.00	.01	

Note. Proportional cost = (Switch RT − No-switch RT)/No-switch RT.

group, $F(1, 38) = 4.90$, $p < .05$; cue–target interval, $F(3, 114) = 9.43$, $p < .0001$; and task switch, $F(1, 38) = 17.53$, $p < .0005$, and a significant interaction of cue–target interval and task switch, $F(3, 114) = 8.46$, $p < .0001$. In addition, the interaction of task switch and group was marginally significant, $F(1, 38) = 3.61$, $p = .07$. These results indicate that the error rates in the switch condition were reduced by increasing cue–target interval (.07, .05, .03, and .03 for the four cue–target intervals, respectively). Although the trend in the no-switch condition was similar in direction, it was much smaller (.02, .01, .01, and .01, respectively) and was not statistically significant. In addition, the patients committed .07 errors in the switch condition and .02 errors in the no-switch condition, whereas the control participants committed .02 and zero errors in the two conditions, respectively. Of importance, the patterns of RT and errors were similar, ruling out speed–accuracy tradeoff as an explanation of the RT results.

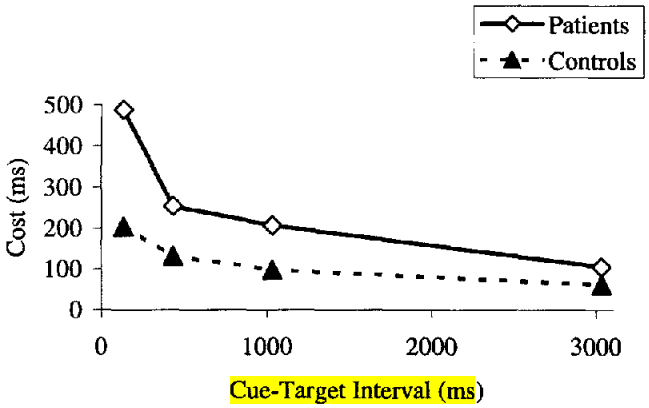

Figure 2. Task-switching cost (in milliseconds) as a function of cue–target interval (in milliseconds) and group in Experiment 1.

Error type. Because the participants made very few errors, we collapsed the results across cue–target interval (see Table 3). Three error types are identifiable. The first type is choice errors (e.g., responding "right" instead of "left"). These errors reflect the incorrect application of the correct task rule. Task errors (e.g., responding "up" instead of "right" to an upper right target) reflect the correct application of the incorrect task rule. Finally, complete errors (e.g., responding "down" instead of "right" to an upper right target) reflect the incorrect application of the incorrect task rule.

The first noteworthy aspect about these results is that participants barely made any complete errors. Moreover, the patients committed more errors than the controls; switching tasks increased all types of errors, and this increase was similar in the two groups. Given the very few complete errors, we conducted two 2-way ANOVAs (Task Switch × Group) on the number of choice errors and task errors as dependent variables. In both cases, only task switch was significant, $F(1, 38) = 5.61, 16.26$, $p < .05$, for choice errors and task errors, respectively. In other words, the analysis of error types did not indicate that the patients had more difficulty than the controls in task switching.

Discussion

The findings can be summarized as follows. First, task switching was associated with RT cost, task-errors cost

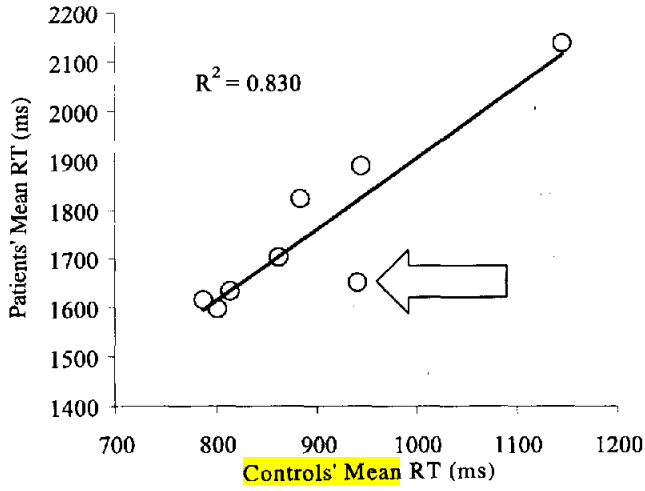

Figure 3. Brinley plot of patients' mean reaction time (RT; in milliseconds) as a function of the controls' mean RT (in milliseconds) for Experiment 1.

Table 3
Mean Number of Errors According to Condition for Experiment 1

	Choice errors		Task errors		Complete errors	
Group	Switch	No-switch	Switch	No-switch	Switch	No-switch
Patients	4.8	2.6	5.1	0.7	0.4	0.1
Controls	1.2	0.5	2.5	0.4	0.3	0.0

(suggesting interference from the previously relevant, but now irrelevant, task set), and choice-errors cost (suggesting that the relevant task set was not fully prepared). Furthermore, task-switching cost was reduced, but not eliminated, by increasing the preparatory (cue–target) interval. It is noteworthy that task-switching cost was not eliminated by preparation, even among the control group. This finding contrasts with previous results on normal young adults indicating an elimination of switching costs in the longest cue–target intervals (Meiran, in press-b). The present control group differed, however, from the participants in Meiran's study (university students) in two respects: The participants in the current experiment had lower education and higher mean age.

Of most importance, the present results indicate that the schizophrenia patients suffered larger switching costs. However, with one exception, the larger switching costs can be explained by the patients' general response slowing, as indicated by the Brinley plot analysis. This analysis showed that most of the variance in the patients' means could be explained by the parallel variance in the control group means. This suggests that the cue–target interval and task switch had similar effects in the two groups, except for generally slower responses among the patients.

Experiment 2

Two interrelated goals were addressed in Experiment 2. First, we wanted to examine further the issue of whether schizophrenia is associated with task-switching difficulties. Second, task-switching performance has several component processes (Goschke, in press; Meiran, 1996, in press-a, in press-b; Meiran et al., in press; Rogers & Monsell, 1995), and we wished to examine additional components to those studied in Experiment 1. Specifically, switching deficits could be composed of a set-engagement component, studied in Experiment 1, and a set-disengagement component, examined in Experiment 2.

The fact that general slowing is one possible explanation of most of the results of Experiment 1 does not prove the hypothesis to be correct. To examine the issue further, we studied task-set disengagement (e.g., Allport et al., 1994). There is evidence suggesting that schizophrenia is associated with poor set disengagement. For example, Elliot et al. (1995, 1998) have shown that schizophrenia patients performed poorly when required to ignore a previously relevant dimension.

To assess the rate of set disengagement, we manipulated the period during which the participants waited for the instructional cue: the response–cue interval. Given the random ordering of the tasks, the participants did not know which task was next and were therefore unlikely to actively prepare during the response–cue interval. Moreover, if the task set from Trial $N - 1$ dissipated during the waiting period, this would have made it easier to switch to a new task set and would have reduced switching costs. Hence, a reduction in switching costs due to an increase in the response–cue interval would indicate disengagement from the task set in Trial $N - 1$. The relevant index is the interaction between task switch and response–cue interval. If schizophrenia was associated with slow set disengagement, patients would exhibit a relatively slow rate of reduction in switching costs as a function of the response–cue interval. The relevant index to measure this prediction is the triple interaction between group, task switch, and response–cue interval.

Method

Participants. As in Experiment 1, there were more men than women in the patient group, and the reverse was true for the control group; this difference did not approach statistical significance ($p = .17$, Fisher's exact test). Therefore, RT was analyzed with sex as an additional independent variable, and neither its main effect nor its interactions were significant. Likewise, the group differences in mean age or in mean years of education did not approach significance in t tests. The PANSS means as well as the mean drug dosage were similar to those in Experiment 1.

Procedure. The procedure was similar to that used in Experiment 1, except that response–cue interval was manipulated instead of cue–target interval. Cue–target interval was fixed at 132 ms. In addition, response–cue interval was fixed for the entire block of trials and varied between blocks. The order of response–cue intervals (316, 816, 1,516, and 3,016 ms) was randomly determined for each participant. Thus, the cue–target interval, manipulated in Experiment 1, changed between trials, and the response–cue interval, manipulated in Experiment 2, changed between blocks of trials. This methodology is based on results from experiments on normal young adults (Meiran et al., in press).

Results

The mean harmonic mean and mean error rates are presented in Table 4.

RT. The 2 × 2 × 4 ANOVA included group, task switch, and response–cue interval as independent variables. The patients responded more slowly than controls, as indicated by the significant main effect of group, $F(1, 38) = 13.23$, $p < .001$. Switching tasks incurred costs, as indicated by the main effect of task switch, $F(1, 38) = 17.67$, $p < .0001$. Moreover, the patients exhibited larger switching costs than controls, as seen in a significant

Table 4
Mean Reaction Time (RT) and Proportion of Errors (PE) for Experiment 2

Response–cue interval	Switch	No-switch	Cost	Proportional cost
		Patients		
316 ms				
RT	1,862	1,508	354	.23
PE	.07	.03	.04	
816 ms				
RT	2,100	1,790	310	.17
PE	.06	.04	.02	
1,516 ms				
RT	1,819	1,646	173	.11
PE	.07	.03	.04	
3,016 ms				
RT	2,009	1,813	196	.11
PE	.06	.03	.03	
		Controls		
316 ms				
RT	1,137	1,087	50	.05
PE	.06	.05	.01	
816 ms				
RT	1,031	920	111	.12
PE	.04	.04	.00	
1,516 ms				
RT	1,069	1,029	40	.04
PE	.04	.06	−.02	
3,016 ms				
RT	1,105	1,043	62	.06
PE	.04	.03	.01	

Note. Proportional cost = (Switch RT − No-switch RT)/No-switch RT.

interaction between task switch and group, $F(1, 38) = 6.24$, $p < .05$. There was evidence for a decrease in switching costs with increasing response–cue intervals, indicated by a significant interaction between response–cue interval and task switch, $F(3, 114) = 2.69$, $p < .05$. Finally, there was also a significant interaction between response–cue interval and group, $F(3, 114) = 7.14$, $p < .0005$. Planned contrasts indicated that the difference between patients and controls in switching costs was significant when response–cue interval was 316 and 816 ms and approached significance when it was 3,016 ms.

The triple interaction was not significant ($F = 1.60$). However, an inspection of Figure 4 strongly suggests that an increase in response–cue interval was associated with a reduction in switching cost among the patients but not among the controls. Accordingly, separate analyses in the two groups indicated that the interaction between response–cue interval and task switch was significant among the schizophrenia patients, $F(3, 57) = 3.08$, $p < .05$, but did not approach significance among the control participants ($F < 1$). The difference between these two trends is measured by the linear component of the triple interaction, and this component was significant, $F(1, 38) = 6.67$, $p < .05$. Because the effect was not predicted, the results should be interpreted cautiously.

As in Experiment 1, we plotted the means of the patients as a function of the corresponding control means. The plot

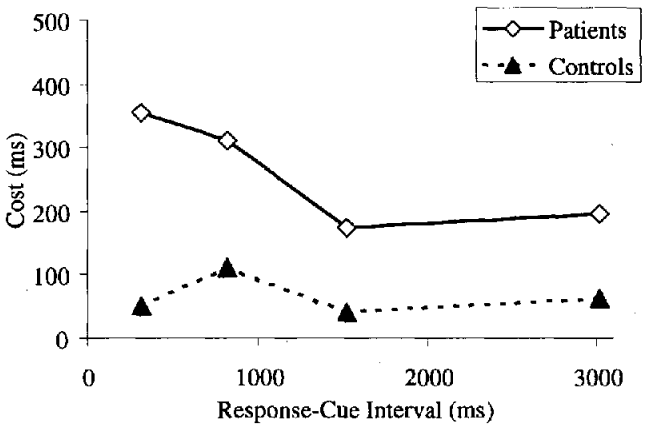

Figure 4. Task-switching cost (in milliseconds) as a function of response–cue interval (in milliseconds) and group in Experiment 2.

of means is presented in Figure 5. Unlike in Experiment 1, only .003 of the variance in the patients' means were explained by the corresponding means in the control group. This result rules out general slowing as an explanation of the increased task-switching cost among patients, at least in the present case.

Error rate. A similar ANOVA on error rates did not identify any significant source of variation. Of importance, the patterns of RT and errors were similar, ruling out speed–accuracy tradeoff as an explanation of the RT results.

Error type. The mean number of errors according to condition are presented in Table 5. As in Experiment 1, there were very few complete errors, and we did not submit them to statistical analysis. The two other error types were analyzed as in Experiment 1. The only significant effect was task switch in the analysis of choice errors, $F(1, 38) = 7.52$, $p < .01$.

Practice effects from Experiment 1. Thirteen of the patients and 14 of the control participants who took part in

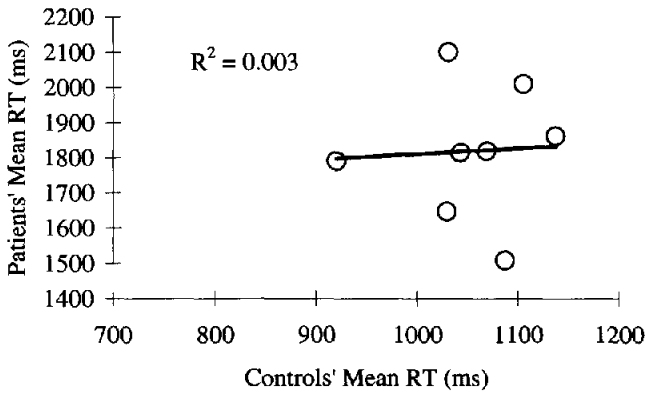

Figure 5. Brinley plot of patients' mean reaction time (RT; in milliseconds) as a function of the controls' mean RT (in milliseconds) for Experiment 2.

Table 5
Mean Number of Errors According to Condition for Experiment 2

	Choice errors		Task errors		Complete errors	
Group	Switch	No-switch	Switch	No-switch	Switch	No-switch
Patients	4.2	2.7	3.9	1.6	0.7	0.2
Controls	2.7	1.5	2.6	2.9	0.7	0.2

Experiment 1 also participated in Experiment 2. The interval between the two experiments ranged between 1 day and 2 months. We therefore conducted an additional ANOVA in which practice (whether the participant had previously participated in Experiment 1) was an additional independent variable. Practice was involved in three significant effects. It had a significant main effect, $F(1, 36) = 8.54$, $p < .01$. Of more interest are the significant interactions between practice and task switch, $F(1, 36) = 7.37$, $p < .01$, and the triple interaction between practice, group, and task switch, $F(1, 36)$, $p < .01$. These interactions indicate that practiced patients suffered less switching cost (1,729 vs. 1,597 ms, or cost of 132 ms) compared with unpracticed patients (2,354 vs. 1,860 ms, or cost of 494 ms). In contrast, practice had no effect on the control participants. In the control group, practice was associated with a switching cost of 67 ms (874 vs. 807 ms), whereas no practice was associated with numerically smaller cost of 62 ms (1,578 vs. 1,516 ms). The results concerning practice should be interpreted with caution because the participants were not assigned randomly to practice. Moreover, results from controlled practice experiments (e.g., Kramer, Hahn, & Gopher, 1999; Meiran, 1996; Meiran et al., in press) indicate that practice reduces switching costs for normal young adults. These results contrast with the present results concerning the control participants. Results concerning patients may suggest that the difference in switching costs between the groups may shrink as a result of practice, as found by Kramer et al. concerning old age.

Discussion

One goal of the present experiment was to examine the rate of task-set disengagement. The prediction was that patients would exhibit slower rate of reduction in switching costs with increased response–cue intervals compared with control participants. On the one hand, the results indicate larger switching costs among the patients, especially in the short response–cue intervals. On the other hand, there was evidence for task-set disengagement among the patients but not among the controls. These results do not indicate that schizophrenia is associated with poor set disengagement. Hence, our conclusions so far are that schizophrenia is not related to poor set engagement or to slow set disengagement. With regard to the present experiment, the larger switching costs among the patients could not be explained by general slowing.

How could these results be explained? Our tentative explanation is that schizophrenia patients suffer difficulties remembering task context. This is consistent with a theory by J. D. Cohen and colleagues (J. D. Cohen, Barch, Carter, & Servan-Schreiber, 1999; J. D. Cohen & Servan-Schreiber, 1992), who attributed patients' impairments in executive functioning to their poor working memory for the task context. J. D. Cohen and Servan-Schreiber (1992) suggested that the poor performance of patients on the WCST might also be explained by poor working memory. Kimberg and Farah (1994), who used a production system metaphor rather than a connectionist metaphor, reached a similar conclusion. In the present experimental paradigm, successful performance depends on remembering the meaning of the four responses. This paradigm therefore differs in an important way from that used in our previous research on normal young adults, in which the meaning of the responses changed with the task. The reason is that these studies used a two-key response setup, where, for example, one response indicated up in the up–down task and left in the right–left task, and the other response indicated both right and down. In the four-key response setup, which we used, pressing a given key always indicated the same meaning (e.g., up). In the four-key paradigm, the best strategy would be to quickly learn response meanings and retain them in memory. This is presumably what the control participants did. However, the patients' failure to retain response meanings made it necessary for them to acquire response meaning information anew in each trial. Presumably, it was easier to reacquire response meaning information when the task was repeated, especially when the response–cue interval was short. This created a transient advantage of no-switch trials, where reactivation was easier, over switch trials, where reactivation was more difficult. Because meaning reactivation probably took time, it resulted in switching cost among the patients but not among the control participants. We therefore suggest that the need to acquire response meaning information anew might be a reason for the larger switching costs seen among the schizophrenia patients compared with their controls. In other words, we suggest that schizophrenia is not associated with a specific task-switching difficulty but that schizophrenia patients' difficulties are a by-product of their poor memory for task context.

An additional set of analyses was run in order to examine whether poor performance in the present paradigm is associated with specific patient characteristics. We therefore computed correlation coefficients between patients' characteristics and several performance indexes. Patients' characteristics included age, sex, education, drug dosage (expressed in chlorpromazine equivalent), and the PANSS scores (six variables in all). Performance indexes included mean RT and error rate in the switch condition and total

number of task errors and total number of choice errors in the no-switch condition. We also included the task-switching cost (collapsed across cue–target interval) expressed in RT, proportion of errors, number of task errors, and number of choice errors (10 variables in all).

Experiment 1. Of the 60 computed correlations, only 4 correlations were significant at the .05 level, whereas 3 significant tests were expected by chance. Given the small number of significant correlations, we decided not to interpret them.

Experiment 2. Six of the 60 correlations were significant at the .05 level. Taking into account that 3 correlations were predicted to be significant by chance, one should interpret the present findings with caution. High drug dosage was associated with an increase in task errors ($r = .59$) and with an increase in the switching cost expressed in task errors ($r = .45$). A high rate of negative symptoms was associated with a slower switch RT ($r = .47$), but this was not specific to task switching because the correlation with RT in the no-switch condition was almost as high ($r = .40$, $p = .07$). Older age was associated with less choice errors ($r = -.46$), smaller switch cost in errors, in general ($r = -.45$), and in choice errors, in particular ($r = -.53$).

To summarize, the correlational analyses do not indicate that switching difficulties, measured in RT costs, which were our primary index, were systematically related to patient characteristics. The results should be interpreted with caution, given the small sample size and range restrictions in some of the variables.

Experiment 3

In Experiment 3, we tested a novel prediction that was based on our account of the results so far. We predicted that if we made it difficult to remember response meanings, normal participants would exhibit a similar pattern of switching cost as that of patients. The present experiment was conducted on two groups of university undergraduates. In Group 1, we used the four-key response setup that was used in the previous experiments, where the meaning of the responses remained constant throughout the experiment. We predicted that switching cost would be relatively small and would not be influenced by response–cue interval, as found for the control participants in Experiment 2. In Group 2, a two-key response setup was used, where the meaning of the responses changed from trial to trial (see Figure 1). For example, the upper left key indicated up in the context of the up–down task, but it indicated left in the context of the right–left task. Presumably, this two-key response setup made it necessary for the participant to acquire response meaning anew in each trial. We suggest that this process mimics the process by which schizophrenia patients perform the task. For reasons of counterbalancing, Group 2 was subdivided into two groups, each using a separate combination of keys (either up–left and down–right or up–right and down–left). The prediction was that switching costs in Groups 2 (two-key setup) would be larger than in Group 1 (four-key setup) and would be significantly reduced by increasing response–cue interval, as found for the patients in Experiment 2.

Method

Participants. Twenty-four undergraduate students took part in the experiment for partial course credit. They were assigned to a group according to the order of entry. Twelve persons were assigned to Group 1, and 12 were assigned to Group 2, of whom 6 were assigned to each key combination.

Procedure. The procedure was similar to that in Experiment 2, except that the four response–cue intervals were 166, 366, 716, and 1,616 ms.

Results

RT. The results were as predicted. Although the pattern of switching costs in Group 1 (four-key setup) resembled that of the control participants in Experiment 2, the pattern of switching costs in Group 2 (two-key setup) resembled that of the schizophrenia patients in Experiment 2. Specifically, in Group 1, switching costs were small and were not significantly influenced by response–cue interval. In contrast, in Group 2, costs were larger and were significantly reduced by response–cue interval.

The 2 × 2 × 4 ANOVA included group (1 vs. 2), task switch (switch, no-switch), and response–cue interval as independent variables. There were significant main effects of task switch, $F(1, 22) = 36.85$, $p < .0001$, and response–cue interval, $F(3, 66) = 3.16$, $p < .05$. These effects were qualified by a significant two-way interaction between response–cue interval and task switch, $F(3, 66) = 2.83$, $p < .05$, and a significant triple interaction, $F(3, 66) = 3.40$, $p < .05$. Separate analyses within each group indicated that the simple two-way interaction between task switch and response–cue interval was significant in Group 2 (two-key setup), $F(3, 33) = 3.87$, $p < .05$, but not in Group 1 (four-key setup, $F < 0.40$). Moreover, the linear component of the triple interaction was significant, $F(1, 22) = 6.47$, $p < .05$ (see Table 6 and Figure 6).

Error rate. A similar analysis on error rates indicated a significant effect of task switch, $F(1, 22) = 13.99$, $p < .005$, indicating an error cost.

Discussion

We accounted for the results of Experiments 1 and 2 by suggesting that schizophrenia is not related to either set-engagement deficits or to set-disengagement deficits. Rather, schizophrenia is related to difficulties in maintaining task context information in memory. In particular, we suggest that schizophrenia patients fail to remember the meaning of responses and therefore need to acquire them anew in each trial. To test this hypothesis, we created conditions in which normal participants could not retain response meanings and needed to acquire them anew in each trial. These conditions mimicked what we believe happens among schizophrenia patients. The present experiment was similar to Experiment 2, but the participants were

Table 6
Mean Reaction Time (RT) and Proportion of Errors (PE) for Experiment 3

Response–cue interval	Switch	No-switch	Cost	Proportional cost
Group 1 (four-key setup)				
166 ms				
RT	761	704	57	.08
PE	.05	.02	.03	
366 ms				
RT	715	669	46	.07
PE	.04	.03	.01	
716 ms				
RT	699	654	45	.07
PE	.04	.02	.02	
1,616 ms				
RT	698	643	55	.09
PE	.04	.03	.01	
Group 2 (two-key setup)				
166 ms				
RT	828	706	122	.17
PE	.04	.02	.02	
366 ms				
RT	812	699	113	.16
PE	.04	.02	.02	
716 ms				
RT	772	664	108	.16
PE	.04	.03	.01	
1,616 ms				
RT	662	620	42	.07
PE	.03	.02	.01	

Note. Proportional cost = (Switch RT − No-switch RT)/No-switch RT.

normal young adults. As predicted, Group 2 (two-key response setup), who needed to reacquire response meaning on every trial, exhibited a pattern of switching costs resembling that of the patients in Experiment 2. In contrast, the results of Group 1 (four-key response setup) replicated those of the control participants in Experiment 2. Specifically, in Group 2, switching costs were relatively large when response–cue interval was short and declined rapidly as that interval increased. This pattern of reduction in switching costs may therefore be a marker of the rapid forgetting of information concerning response meaning.

General Discussion

In recent years, there has been an effort to design tasks that isolate set shifting abilities and that minimally tap other abilities. In the present study, we used a task-switching paradigm in which keeping track of past responses and considering feedback was not required. Moreover, task-switching costs have been shown to be unrelated to stimulus repetition effects within modality (e.g., Meiran, 1996). Our results indicate that about one third of the patients were unable to complete the test, whereas all control participants completed the test successfully. The patients who completed the test suffered greater switching costs than the control participants. In one condition, the difference in switching cost could be explained by response slowing. We refer to conditions in which there was sufficient time to prepare for a task switch (Experiment 1, long cue–target interval). However, when the time to prepare was short, response slowing could not account for the increase in switching costs. We examined several component processes associated with task switching and found that the patients were as efficient as the control participants in preparing for a task switch. This was indicated by a normal (in fact, faster) rate of reduction in switching costs as a function of preparation time. Moreover, the patients were no slower than the control participants in disengaging from the task set adopted in the previous trial. Set-disengagement rate was inferred from the rate of reduction in switching costs as a function of the response–cue interval.

Our interpretation of the results is that schizophrenia patients do not have a specific switching deficit. Instead, their task-switching difficulties result from a broader difficulty in active memory for task context. Specifically, the reason why the patients suffered greater switching costs or could not do the test may be related to their difficulty remembering response meaning. This was indicated by their overt verbalizations, their reminding themselves, or their needing to be reminded by the experimenter what the responses indicated. Another indication was the patients' relatively fast rate of reduction in switching costs caused by increasing the response–cue interval, combined with their relatively high cost when that interval was short. Although the triple interaction between group, response–cue interval, and task switch was nonsignificant, its critical linear component was significant. This pattern of switching costs suggests that the patients needed to acquire response meaning anew in each trial and that the information was rapidly lost from memory (see *Discussion* of Experiment 2). In Experiment 3, we supported this interpretation of the results by testing normal young adults. We created a condition in which normal participants needed to acquire response

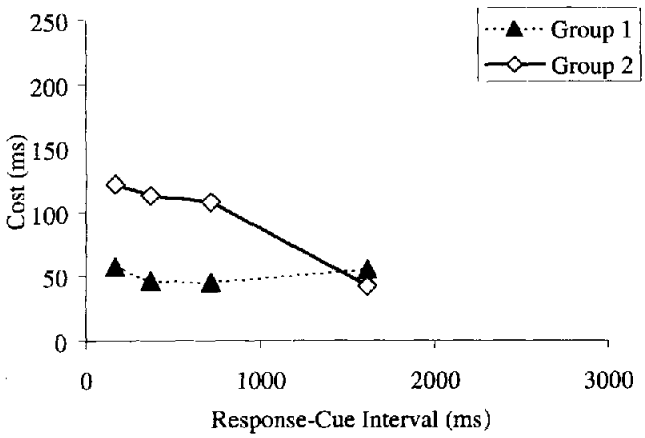

Figure 6. Task-switching cost (in milliseconds) as a function of response–cue interval (in milliseconds) and group in Experiment 3. The participants in both groups were university students. Group 1 used the four-key response setup and Group 2 used the two-key response setup.

meaning anew in each trial (two-key setup), thereby simulating the difficulties that the patients presumably had. In that condition, the pattern of switching costs resembled the pattern found among the patients in Experiment 2. In Experiment 3, we also replicated the pattern of switching costs found among the control participants in Experiment 2 (four-key setup), showing relatively small costs that were barely influenced by response–cue interval.

Our account of the results of Experiment 2 can also explain the fact that in Experiment 1, the patients exhibited a faster-than-normal rate of task preparation. Specifically, increasing the cue–target interval led to a sharper reduction in switching costs among the patients than among the controls. This pattern may indicate that the patients had to prepare more components of the task during the cue–target interval as compared with the control participants. One task component possibly prepared by both groups is reorienting to the relevant stimulus dimension and ignoring the irrelevant dimension (e.g., attending to the vertical dimension while ignoring the horizontal dimension; see Meiran, in press-a, in press-b). However, unlike the control participants, the patients presumably had an additional task component to prepare on switch trials because they needed to reactivate response meaning information. Having an additional component to prepare for resulted in larger switching costs and a larger reduction in switching costs as a result of preparation. Results by Meiran (in press-b) support our interpretation. The study was conducted on normal adults and compared the two-key response setup with several four-key response setups with a manipulation of cue–target interval. The findings indicated (a) larger switching costs and (b) stronger influences of preparation on switching costs with the two-key setup as compared with the four-key setup. These results suggest that normal participants, who use the two-key response setup, also produce a pattern of switching costs resembling that of schizophrenia patients when cue–target interval is manipulated.

Although the present results do not indicate a problem in task switching per se, one should keep in mind that not all the possible component processes involved in task switching were examined. One important component that was not examined is mixing cost (Fagot, 1994; Los, 1999; Meiran et al., in press). Mixing cost refers to the difference between no-switch trials and a condition in which participants perform a single task and do not switch tasks. As the term implies, mixing cost indicates the performance decrement associated with the fact that trials of two tasks are intermixed. It is quite likely that mixing tasks causes a large performance decrement for schizophrenia patients, which may explain the relatively large number of patients failing to complete the test in mixed tasks conditions. Difficulties in remembering task context should be inflated when task context becomes more complicated, as when mixing tasks. Further research is required to address this possibility. The present results suggest, however, that once patients can deal with mixed task conditions, their ability to switch between the tasks is relatively unimpaired.

The notion that schizophrenia patients fail to remember response meaning is similar to the suggestions regarding set-maintenance problems in these patients, seen also in their WCST performance (Fey, 1951). J. D. Cohen and colleagues (J. D. Cohen et al., 1999; J. D. Cohen & Servan-Schreiber, 1992) presented a detailed model that explains most of the patients' difficulties in executive functioning by their poor memory for the global task context.

If our account of the results is correct, it has important implications for theories of task switching. We used the cuing version of the task-switching paradigm, where memory demands were presumably equal for switch trials and no-switch trials. This assumption is based on the fact that both trials were included in the same block of trials (see Meiran, 1996; Rogers & Monsell, 1995). However, our account of the present results suggests that there is an unequal memory demand with the two-key response setup. Specifically, it seems that memory demand is smaller for no-switch trials than for switch trials. This is especially true when response–cue interval is short because response meaning information is already available in no-switch trials. In contrast, switch trials require reactivation of response meaning information.

We acknowledge the fact that these conclusions may not necessarily be generalizable to other patient populations because the patients in this study suffered from schizophrenia and were medicated for long periods before they were tested. Therefore, we cannot rule out the possibility that some of our findings reflected the effects of medication rather than the disease. Nonetheless, the fact that drug dosage was not significantly related to task switching performance in Experiment 1 can be taken as tentative evidence against this interpretation. Furthermore, in Experiment 2, there were two significant correlations with drug dosage, but both involved task error indexes and not RT, which was our principal dependent measure.

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