

# Impairment of willed actions and use of advance information for movement preparation in schizophrenia

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## Abstract

**Objectives**—To assess willed actions in patients with schizophrenia using reaction time (RT) tasks that differ in the degree to which they involve volitionally controlled versus stimulus driven responses.

**Methods**—Ten patients diagnosed with schizophrenia and 13 normal controls of comparable age were tested. Subjects performed a visual simple RT (SRT), an uncued four choice reaction time (CRT), and a fully cued four choice RT task. A stimulus 1(S1)–stimulus 2(S2) paradigm was used. The warning signal/precue (S1) preceded the imperative stimulus (S2) by either 0 (no warning signal or precue) 200, 800, 1600, or 3200 ms.

**Results**—The patients with schizophrenia had significantly slower RTs and movement times than normal subjects across all RT tasks. The unwarned SRT trials were significantly faster than the uncued CRT trials for both groups. For both groups, fully cued CRTs were significantly faster than the uncued CRTs. However, the S1–S2 interval had a differential effect on CRTs in the two groups. For the normal subjects fully cued CRTs and SRTs were equivalent when S1–S2 intervals were 800 ms or longer. A similar pattern of effects was not seen in the patients with schizophrenia, for whom the fully cued CRT were unexpectedly equivalent to SRT for the 200 ms interval and expectedly for the 1600 ms S1–S2 interval, but not the 3200 or 800 ms intervals.

**Conclusions**—Patients with schizophrenia were able to use advance information inherent in SRT or provided by the precue in fully cued CRT to speed up RT relative to uncued CRT. However, in the latter task, in which the volitional demands of preprogramming are higher since a *different* response has to be prepared on each trial, patients showed some unusual and inconsistent interval effects suggesting instability of attentional set. It is possible that future studies using RT tasks with higher volitional demands in patients with predominance of negative signs may disclose greater deficits in willed action in schizophrenia.

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Keywords: schizophrenia; willed action; reaction time; motor preparation

Schizophrenia is a psychiatric disorder characterised by various symptoms.<sup>1</sup> Positive symptoms are those that patients experience and by their presence distinguish patients from normal, such as thought disorder or hallucinations. Negative signs exist when the patients lack some element of normal behaviour—for example, flattening of affect, poverty of speech, and social withdrawal. Frith<sup>2</sup> has suggested that the signs and symptoms of schizophrenia such as poverty of action or stereotyped action reflect a dysfunction of “willed” actions, whereas the processes involved in “stimulus driven” actions remain largely intact. This means that patients can perform routine acts elicited by environmental stimuli, but have difficulty in producing spontaneous behaviour in the absence of external cues.

One way of testing the hypothesis of impairment of willed actions in schizophrenia is to examine the speed of response initiation in reaction time (RT) tasks that differ in the extent to which they require volitionally prepared versus stimulus driven responses. In simple RT (SRT) tasks the same stimulus is presented across trials, and requires the same invariable response. The stimulus-response invariance provides the subject with the option of preparing the response before presentation of the stimulus—that is, to preprogramme it. In SRT, this preprogramming is an optional and volitional process, which has been shown to require attention as it is susceptible to interference from the concurrent performance of a secondary task.<sup>3,4</sup> By contrast, in an uncued choice RT (CRT) task, in which there are several stimuli each indicating a different response, the response is elicited by presentation of the imperative stimulus. In uncued CRT, the response is selected and programmed after presentation of the stimulus, so it is considered to be stimulus driven. Volitional preprogramming is not possible in uncued CRT, but is a requirement in fully precued CRTs. In a fully cued CRT task a precue provides the subject with full advance information about the particular response required on that trial that allows its selection and preprogramming before the presentation of the imperative stimulus. The SRT and the fully cued CRT differ on one important factor: stimulus-response (S-R) variance. In the SRT the stimulus and response are the same on every trial, therefore the subject can preprogramme the same response for every trial. In the fully cued CRT, although full movement information is provided by the

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precue, the subject must preprogramme a *different* response for each trial.

There have been studies of RTs in schizophrenia since the 1930s.<sup>5</sup> The most consistent finding is that schizophrenic patients have significantly slower RTs than normal controls.<sup>6-8</sup> Another consistent finding is the "cross over effect" (COE), reported as far back as the 1940s.<sup>9</sup> In normal subjects, in a simple RT (SRT) task, if the interval between the warning signal (S1) and imperative stimulus (S2) is short ( $\leq 3$  seconds), responses are initiated faster on trials where the S1-S2 interval is kept constant or blocked rather than presented randomly across trials. This improved performance is thought to be due to the temporal predictability of the imperative stimulus. However, with longer S1-S2 intervals, normal subjects have similar RTs regardless of whether the S1-S2 intervals are random or blocked. Patients with schizophrenia generally show the same RT benefit from temporal predictability when S1-S2 intervals are short. By contrast, when the S1-S2 intervals are longer, patients with schizophrenia have slower RTs for the blocked S1-S2 intervals than for the random S1-S2 intervals. This phenomenon is called the COE.

In the COE the patients with schizophrenia are failing to use the advance information provided by the warning signal about the temporal predictability of the imperative stimulus to speed up the response. Few studies have examined the effect of other types of advance information on RTs in schizophrenia—for example, the use of advance movement parameter information contained in a precue that allows volitional preprogramming of the response before presentation of the imperative stimulus. Carnahan *et al.*<sup>10</sup> measured RTs in leukotomised and unleukotomised schizophrenic patients compared with normal controls. Using a version of Rosenbaum's RT paradigm,<sup>11</sup> the authors measured RT in uncued, partially cued, and fully cued four choice RT (CRT) conditions. The two schizophrenic groups were slower than the normal subjects across all RT conditions. The authors concluded that "the leukotomised and the unleukotomised schizophrenics were able to use this advance information to facilitate the speed of their responses in much the same way as did subjects in a normal control group".

The type of information provided by a preparatory signal (S1) presented before an imperative stimulus (S2) can vary. Any signal given a short time before an imperative stimulus will serve as a warning to the subject, allowing them to increase their level of alertness and readiness to respond. This facilitation seems to be optimal with a preparatory interval of 200 ms.<sup>12</sup> Alternatively, the preparatory signal may provide advance information about the nature of the response itself—for example, it may inform the subjects that they have to move to the upper key with their right hand when the imperative stimulus is presented. In this case it may be referred to as a movement parameter precue. This information potentially allows the subject to preselect and preprogramme a

specific response from a number of alternatives, provided there is adequate time between the precue and the imperative stimulus to take action. The amount of reduction of RT by warning stimulus and movement parameter precues also depends on when they are presented relative to the imperative stimulus. Therefore, the interval between the warning signal/precue and the go signal is important in determining the RT facilitation.

The aim of this study was to examine the effects of different types of advance information on RT in schizophrenia: (1) invariance of the stimulus and response in SRT relative to uncued CRT, (2) full advance movement parameter information in a precued CRT task. We were also interested in determining if the interval between the warning stimulus/precue (S1) and the imperative stimulus (S2) had similar or differential effects on motor preparation in schizophrenic patients and normal subjects.

## Methods

### DESIGN

A mixed between group and within subject design was used. The two groups of subjects, patients with schizophrenia or healthy normal controls, performed a series of reaction time (RT) conditions: simple reaction time (SRT), uncued four choice RT (CRT), fully cued CRT, and retest of SRT. In each RT condition, an S1-S2 paradigm was used. For each condition, trials were either unwarned (S1-S2 interval of 0 ms) or the imperative stimulus followed the warning signal/precue, with S1-S2 intervals of 200, 800, 1600, or 3200 ms.

### SUBJECTS

The characteristics of the two samples are presented in the table. Ten subjects clinically diagnosed with schizophrenia according to the DSM III R were tested. Each was seen as an outpatient at the National Hospital for Neurology and Neurosurgery. Each patient was rated on a four point standardised psychiatric assessment scale<sup>13</sup> for current positive and negative symptoms. Overall, the patients were chronically ill and their symptoms were not very severe. Thirteen healthy normal subjects with no history of psychiatric or neurological illness, head injury, or drug misuse were tested. The mini mental state examination<sup>14</sup> was administered to all subjects and no one scored below the cut off indicative of cognitive deficit.

### PROCEDURE-REACTION TIME TASKS

A full description of the procedure is available in Jahanshahi *et al.*<sup>15</sup> Responses were made on a response box with six buttons. The two centre black buttons acted as the home keys. Four inches above and 4 inches below each black button were the response buttons. Stimuli were presented on a 14 inch computer screen. A variation of Rosenbaum's<sup>11</sup> movement precueing RT was used. The subject pressed down the two home keys to begin the trial and a fixation point appeared. The warning stimulus appeared after a variable delay of 1-4 seconds. The imperative stimulus (S2) appeared after

## Details of subject groups

	Patients with schizophrenia	Controls
Sex:		
Male	8	8
Female	2	5
Hand:		
Right	10	13
Left	0	0
Mean age (y)	37.9 (8.0)	38.9 (10.1)
Mean mini mental state scores	28.0 (2.5)	29.9 (0.6)
Mean duration of illness (y)	13.1 (7.0)	
Krawiecka scale (1977):		
Positive symptoms (range 0–8)	2.0 (2.8)	
Negative symptoms (range 0–5)	2.1 (1.6)	
	Daily dosage (SD)	(n)
Neuroleptic drugs:		
Chlorpromazine equivalent	372.5 mg (151.8)	(8)
Anticholinergic drugs:		
Disipal equivalent	150.0 mg (0.0)	(2)
Tricyclic antidepressant drugs:		
Lofepamine	140.0 mg	(1)
No medication		(2)

Values in parentheses are SD.

the S1–S2 interval (200, 800, 1600, or 3200 ms). On unwarned trials (S1–S2 interval of 0 ms) there was no warning stimulus.

Three types of error trials were recorded: anticipations ( $RT \leq 100$  ms), long responses ( $RT > 3$  s), decision errors (incorrect responses in CRT). RT and movement time (MT) from these trials were omitted, and the trials were repeated—that is, trials on which errors occurred were omitted from calculation of mean RTs, but to ensure equal number of trials across subjects any trials with errors were replaced by administering an additional trial. RT was measured (in ms) as the time between the presentation of the imperative stimulus and the release of the home key. MT was measured (in ms) as the time between releasing the home key and pressing the response key. The mean RT for each condition for each subject were used in the analyses.

#### Simple reaction time (SRT)

The stimulus and the response were constant across trials within a block. The subject moved from one home key to one response key, and all other keys were covered. Each subject performed two blocks of 50 trials (10 trials per interval), one block with each hand. The order of testing the left or right hand was counterbalanced across subjects in each group—that is, in the groups of patients with schizophrenia half of the subjects performed the test with their right hand first and half used their left hand first. Similarly, within the group of normal subjects the order of left and right hands was counterbalanced. At the end of the experiment, the SRT condition was presented again to assess possible fatigue or practice effects. Within a block of 50 trials, S1–S2 intervals of 0, 200, 800, 1600, and 3200 ms were randomly presented, 10 trials each.

#### Four choice reaction time (CRT)

There were two movement parameters, hand (right or left) and direction (up or down). The two conditions were either uncued or fully cued. In each condition there were 75 trials with 15 trials of each of the five S1–S2 intervals randomly mixed in a block. A similar and ran-

domly mixed number of right and left hand responses were incorporated.

#### Uncued CRT

The warning stimulus consisted of four empty squares appearing to the left and right and above and below the fixation cross. After the S1–S2 interval one square filled which became the imperative stimulus.

#### Fully cued CRT

One empty square appeared in one of the four possible locations above or below, to the left or right of the fixation point. After the S1–S2 interval the square filled to become the imperative stimulus. Thus the subject knew the precise nature of the required response before the presentation of the imperative stimulus.

#### Order of testing

The SRT condition was performed first followed by the CRT conditions. The order of performance of the CRT conditions was counterbalanced across subjects in each group. We considered counterbalancing more appropriate than randomising because for theoretical reasons we wanted subjects to perform SRT before the CRT tasks so as not to influence the S–R invariance of SRT by prior exposure to CRT with multiple stimuli and responses. Subsequently, we counterbalanced the order of testing of the CRT tasks.

#### STATISTICAL ANALYSIS

Mean RTs were used for further analysis. The data were analysed using the Statistical Program for Social Sciences (SPSS), version 8.0. Differences between RTs for the left versus right hand were examined using repeated measures analysis of variance (ANOVA) with group as the between subjects factor and hand (left, right), condition (SRT, uncued CRT, fully cued CRT), and S1–S2 Interval (0, 200, 800, 1600, 3200 ms) as the within subject factors. For both groups, although RTs for the right hand were (non-significantly) faster than those for the left hand, there were no interaction effects of hand with any other variable (group, condition, S1–S2 interval). The data for the left and right hands were averaged for each condition. This average was used in all subsequent analyses.

*t* Tests were used to further investigate significant interactions in the ANOVAs. When *t* tests were used equal variances were not assumed. Paired *t* tests were used to examine within subject measures and independent *t* tests were used for between group measures.

To compare the difference between the true SRT and CRT conditions, data from the trials with an S1–S2 interval of 0 ms—that is, without a warning signal, were analysed using a repeated measures ANOVA. The between subject factor was group (patients, controls) and the within subject factors were condition (SRT (0 ms S1–S2 interval) and uncued CRT (0 ms S1–S2 interval)).

To examine the effects of advance movement parameter information on CRT, the differences between the uncued and fully cued CRT were

examined using a repeated measures ANOVA. The between subject factor was group (patients, controls). The within subject factors were condition (uncued CRT, fully cued CRT), and interval (200, 800, 1600, 3200 ms).

The effects of using two types of advance information on RT were examined by directly comparing SRTs which can involve volitional and optional use of advance knowledge about S-R invariance for preprogramming of the response before stimulus presentation, and the fully cued CRT in which the precue provides full information about the specific response required on that trial which allows its selection and preparation before presentation of the imperative stimulus. A repeated measures ANOVA was used with group (patients, controls) as the between subject factor and condition (SRT, fully cued CRT), and interval (200, 800, 1600, 3200 ms) as the within subject factors.

Movement time was analysed using a repeated measures ANOVA. The between subject factor was group (patients, controls) and the within subject factors were condition (SRT, uncued CRT, fully cued CRT) and Interval (0, 200, 800, 1600, 3200 ms).

Error data were analysed using Mann-Whitney *U* tests for the between groups comparisons and Wilcoxon matched pairs test for the within subject analyses.

## Results

The two groups did not differ in age ( $t=0.25$ ,  $df=21$ ,  $p=0.80$ ) or male to female ratio ( $\chi^2=0.25$ ,  $df=1$ ,  $p=0.62$ ). Although the groups differed on scores on the mini mental examination ( $t=2.5$ ,  $df=21$ ,  $p=0.05$ ), no subject scored below the cutoff of 25.

Fatigue or practice effects were assessed by comparing SRTs performed at the beginning and end of the session. The controls had a mean RT of 351 (SD 57) ms for the first SRT and a mean RT of 373 (SD 63) ms for the final SRT, a mean difference of 22 (SD 33) ms. The mean RT of the patients with schizophrenia was 442 (SD 105) ms for the first SRT and 474 (SD 104) ms for the final SRT, a mean difference of 17 (SD 21) ms. There was no significant difference between the change in RT between the two groups ( $t=0.41$ ,  $df=20$ ,  $p=0.69$ ).

### ERROR DATA

Very few errors of any type were made by the patients or normal subjects. In the SRT for the schizophrenic group, the median number of anticipation errors was 0.10 (range 0.00–0.80) and the median number of long responses was 0.00 (range 0.00–0.10). For the controls, for SRT, the median number of anticipation errors was 0.10 (range 0.00–0.40) and the median number of long responses was 0.00 (range 0.00–0.20). Across the CRT conditions, the schizophrenic group had a median of 0.10 (range 0.00–3.50) anticipation errors, 0.00 (range 0.00–0.30) long responses, and 0.10 (range 0.00–0.10) decision errors. Across the CRT conditions, the controls had a median of

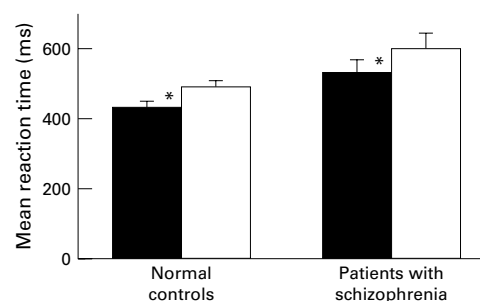


Figure 1 Mean reaction time for the normal subjects and the patients with schizophrenia in the unwarned simple reaction time (SRT) (black bar) and the uncued and unwarned choice reaction time (CRT) (open bar) tasks.

0.01 (range 0.00–0.20) anticipation errors, 0.00 (range 0.00–0.15) long responses, and 0.00 (range 0.00–0.20) decision errors.

A series of Mann-Whitney *U* tests showed that there were no significant differences between the patients and controls in the number of anticipations, decision errors, or long responses in the various RT conditions ( $p>0.05$ ). Similarly, Wilcoxon matched pairs tests showed that there were no differences in errors between the various RT conditions for the patients with schizophrenia ( $p>0.05$ ). For the controls, there were more anticipation errors in the SRT compared with the uncued CRT ( $Z=2.5$ ,  $p=0.01$ ) but not in the fully cued CRT ( $Z=1.21$ ,  $p=0.22$ ) conditions. Also, for the controls there were more anticipation errors in the fully cued CRT than in the uncued CRT ( $Z=2.6$ ,  $p=0.01$ ).

### UNWARNED SRT VERSUS UNWARNED AND UNCUED CRT

The mean RTs for the two groups in unwarned SRT and unwarned and uncued CRT conditions are presented in figure 1. The group effect was significant ( $F(1,20)=7.94$ ,  $p=0.01$ ) with patients with schizophrenia having slower reaction times than the controls. The condition effect was significant ( $F(1,20)=18.16$ ,  $p=0.001$ ) with SRTs being faster than CRTs; however the group $\times$ condition interaction was not significant ( $p>0.1$ ). To determine if the speeding up of SRT relative to CRT which is an index of preprogramming was equivalent in the two groups, the differences in RT between the two conditions were examined using paired *t* tests for each group. The mean differences between the CRT and SRT conditions was 60.3 (SD 50.6) ms for the controls and 69.1 (SD 91.8) ms for the patients with schizophrenia. The unwarned SRT was significantly faster than the uncued and unwarned CRT for both the controls ( $t=4.30$ ,  $df=12$ ,  $p=0.01$ ) and the patients with schizophrenia ( $t=2.30$ ,  $df=8$ ,  $p=0.05$ ).

### UNCUED CRT VERSUS FULLY CUED CRT

The mean RTs for the two groups for the uncued and fully cued CRT are presented in figure 2. The main effects of group ( $F(1, 21)=8.32$ ,  $p=0.01$ ), condition ( $F(1, 63)=69.92$ ,  $p=0.001$ ), and interval ( $F(3, 63)=13.23$ ,  $p=0.001$ ) were significant. The group $\times$ condition interaction was not significant ( $p<0.05$ ). By



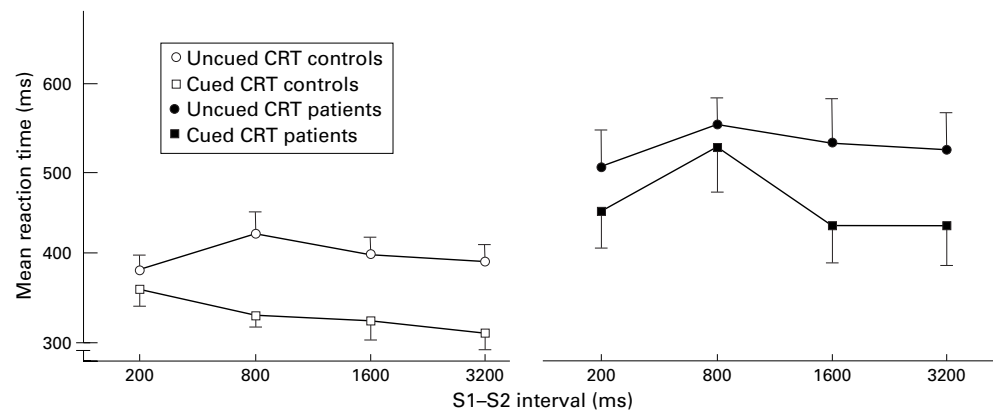


Figure 2 Mean reaction times for the normal subjects and the patients with schizophrenia in uncued (circle), and fully cued (square) CRT conditions.

contrast, the condition $\times$ interval ( $F(3, 63)=5.18$ ,  $p=0.003$ ), the group $\times$ interval ( $F(3, 63)=4.84$ ,  $p=0.004$ ) and the group $\times$ condition $\times$ interval ( $F(3, 63)=4.29$ ,  $p=0.01$ ) interactions were significant.

Further analysis of the condition effect showed that across the two groups and the various intervals, the uncued CRT was significantly slower than the fully cued condition ( $p=0.001$ ). The significant main effect of interval was also examined in more detail. Across the two groups, RTs for the 800 ms S1-S2 interval were slower than those for the 200 ms ( $p=0.01$ ), the 1600 ms ( $p=0.001$ ) and the 3200 ms ( $p=0.001$ ) intervals. No other intervals differed significantly.

Further analysis of the group $\times$ interval interaction showed that for the control subjects RTs for the 3200 ms intervals were faster than those for the 200 ms ( $p=0.04$ ) and the 800 ms interval ( $p=0.002$ ). By contrast, for the patients with schizophrenia RTs for the 800 ms interval were slower than those for the 200, 1600, and 3200 ms intervals ( $p<0.01$ ) and no other intervals differed ( $p>0.05$ ).

Further analysis of the group $\times$ condition $\times$ interval interaction disclosed that across the two CRT tasks for the controls subjects fully cued CRT were significantly faster than the uncued CRT at each interval (200, 800, 1600, and 3200 ms) ( $p<0.02$ ). On average for the normal subjects, the fully cued CRT was faster than the uncued CRT by 19.9, 83.1,

68.7, and 73.4 ms respectively with the 200, 800, 1600, and 3200 ms S1-S2 intervals. Thus the differences between the two CRT conditions at the 200 ms interval, although small (mean 19.9 (SD 24.5) ms), reached significance. For the patients with schizophrenia the RTs for the fully cued CRT were significantly faster than the CRTs for the uncued CRT for the 1600 ms (faster on average by 86 ms) and 3200 ms (faster on average by 77.4 ms) intervals ( $p<0.01$ ) only.

#### SRT VERSUS FULLY CUED CRT

The mean RTs for the two groups for the SRT and fully cued CRT are shown in figure 3. The main effects of group ( $F(1, 20)=7.60$ ,  $p=0.01$ ), condition ( $F(1, 20)=12.19$ ,  $p=0.002$ ), and interval ( $F(3, 60)=11.89$ ,  $p=0.001$ ) were significant. The group $\times$ condition interaction ( $F(1, 20)=2.35$ ,  $p=0.14$ ) was not significant. The condition $\times$ interval ( $F(3, 60)=2.80$ ,  $p=0.05$ ), group $\times$ interval ( $F(3, 60)=3.43$ ,  $p=0.02$ ), and the group $\times$ condition $\times$ interval ( $F(3, 60)=9.52$ ,  $p=0.01$ ) interactions were significant.

The significant three way interaction was examined further by investigating differences between SRT and fully cued CRT for each of the four intervals within each group. For the normal subjects, fully cued CRTs were significantly slower than SRTs at the 200 ms interval ( $p=0.001$ ) but not at the 800, 1600, or 3200 ms intervals ( $p>0.1$ ). By contrast, for the patients with schizophrenia, CRTs were significantly

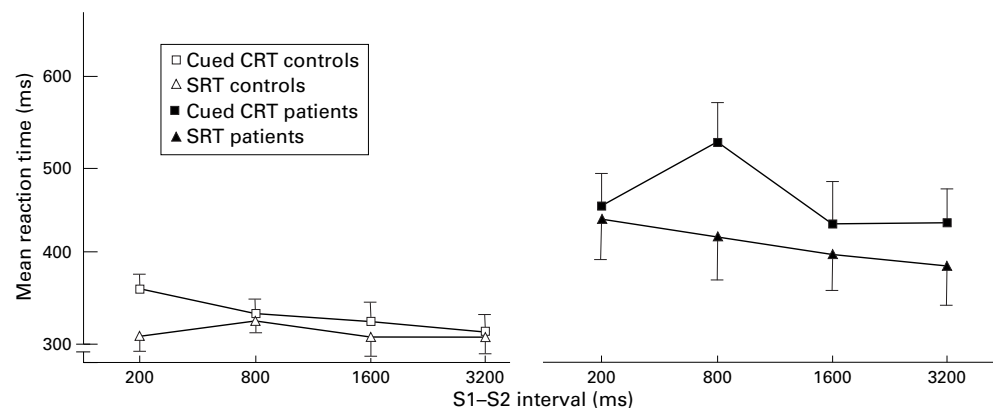


Figure 3 Mean reaction times for the normal subjects and the patients with schizophrenia in SRT (triangle) and fully cued CRT (square) conditions.

slower than SRTs for the 800 ( $p=0.01$ ) and the 3200 ms interval ( $p=0.04$ ) but not for the 200 or the 1600 ms S1-S2 intervals ( $p>0.1$ ).

#### MOVEMENT TIME

The main effects of group ( $F(1,20)=8.29$ ,  $p=0.01$ ) and condition ( $F(2,31)=10.67$ ,  $p=0.001$ ) were significant, but not the main effect of interval ( $F(3,54)=1.94$ ,  $p=0.14$ ). There were no significant interaction effects ( $p>0.05$ ). The patients with schizophrenia had slower MTs (278 (SD 68) ms) than the controls (190 (SD 73) ms). MTs were significantly faster in the SRT condition compared with each CRT condition ( $p<0.05$ ). The two CRT conditions did not differ.

#### Discussion

Overall, the RTs and MTs of patients with schizophrenia were significantly slower and more variable than those of age matched normal subjects across all conditions. Unwarned SRT were significantly faster than the uncued CRT in both groups. For both groups the fully cued CRTs were significantly faster than the uncued CRTs. There was a curious interval effect for the patients with schizophrenia which resulted from the fact that in the fully cued CRT condition, the patients with schizophrenia had CRTs which were significantly faster at the 200 ms than the 800 ms interval. Besides significant slowness in movement initiation and execution, significant differences in interval effects were the main factors that distinguished the various RTs of the patients and controls.

Before we discuss the main results further we will consider and exclude the possible effects of confounding factors on the RT results. As it was not possible to test the patients with schizophrenia not taking medication, there is always the possibility that the results obtained are affected by the medication that eight of the 10 patients were taking. Most existing studies have found no effect of neuroleptic medication on RTs.<sup>16-20</sup> Nevertheless, in an RT paradigm with auditory stimuli, RTs were significantly lower for schizophrenic patients on medication than in those not taking medication.<sup>21</sup> Whereas the first results suggest that medication status may not affect RTs, the second study suggests that the slowing of RTs in schizophrenia may be partly attributable to the neuroleptic medication that is taken by most patients. If this is the case, then RTs should be assessed in drug free patients, a procedure which is not feasible in most studies for clinical reasons. In the present study, there was some indication that the RTs of the two patients who were not taking any medication at the time of the study were in fact somewhat slower than those of the remaining eight patients taking medication.

For both groups, RTs slowed slightly during the experiment as seen by the increased RT in the final SRT task compared with the initial SRT task. As there was no significant difference between the two groups on the amount of slowing, the results are not confounded by different patterns of fatigue effects in the two groups.

Precueing produced no differential effect on MT, as MTs for uncued and fully cued conditions did not differ significantly. By contrast, precueing or provision of advance movement parameter information, produced a significant effect on RTs. The RTs were significantly faster for the fully cued than for the uncued CRT. The differential effects of precueing on MTs and RTs suggest that the use of advance information for motor preparation is complete by the end of the RT period when the subject lifts his or her index finger from the home key and that there is no evidence of "on line" preparation during movement execution.

The two groups did not differ in the number of anticipations, decision errors, or long responses. Therefore, the differences in RT between the patients with schizophrenia and normal subjects do not seem to be associated with different speed-accuracy trade offs across the two groups

#### USE OF STIMULUS RESPONSE INVARIANCE FOR PREPROGRAMMING IN SRT: SRT VERSUS UNCUEd CRT

The patients with schizophrenia were significantly slower than the controls on both the SRT and uncued CRT tasks. However, for both groups the SRT was significantly faster than CRT. These results suggest that in the SRT condition, which involves optional and volitional preprogramming, the patients with schizophrenia preprogramme the response before presentation of the stimulus. As a result this condition was significantly faster than the uncued and unwarned CRT, which is a purely stimulus driven task in which no preprogramming is possible and the correct response is selected, prepared, and initiated only after presentation of the imperative stimulus. The significant slowness of SRT in schizophrenia relative to normal subjects agrees with the results of previous studies.<sup>22-24</sup> Nuechterlein<sup>25</sup> has reviewed the few studies which have directly compared SRT and uncued CRT in schizophrenia. As with the present results, all previous studies have found that CRT is slower than SRT for patients with schizophrenia, similar to normal subjects. However, the present results also showed that the CRT-SRT difference was similar in the two groups.

#### USE OF ADVANCE MOVEMENT PARAMETER INFORMATION FOR PREPROGRAMMING IN CRT: FULLY PRECUEd VERSUS UNCUEd CRT OR SRT

The fully cued CRTs were significantly faster than the uncued CRTs for the patients with schizophrenia, similar to the normal subjects. This is in agreement with previous studies suggesting that valid cues are used by patients with schizophrenia to speed up RT.<sup>8, 26</sup> However, the significant group $\times$ interval and group $\times$ condition $\times$ interval interactions when comparing the fully cued CRT with the uncued CRT or SRT, disclosed that the patients with schizophrenia showed anomalies in the use of advance information. Confirming our previous finding<sup>15</sup> for the normal subjects with the RT tasks used, an S1-S2 interval of 200 ms is not long enough for subjects to use advance information to speed

up fully cued CRTs to the level of SRTs. But with S1-S2 intervals of 800 ms or longer, the advance information provided by the precue is fully used by normal subjects to speed up precued CRTs and make these equivalent to the corresponding SRTs. For the patients with schizophrenia an unusual S1-S2 interval effect was present, mainly due to slower fully cued CRTs for the 800 ms and faster fully precued CRTs for the 200 ms S1-S2 interval. As a result, by contrast with the normal subjects, fully precued CRTs were equivalent to SRT even for the 200 ms interval, but not for the longer 800 ms S1-S2 interval or the 3200 ms interval. Examination of the raw data shows that the interval effect found was not caused by a single outlier. Nine of the 10 patients had slower fully cued CRTs for the 800 ms S1-S2 interval relative to the 200 ms S1-S2 interval. This abnormal S1-S2 interval effect may reflect inconsistencies of set in patients with schizophrenia similar to that seen in the cross over effect.<sup>27</sup>

There are some similarities between the current results for patients with schizophrenia and results from patients with Parkinson's disease in our previous study.<sup>15</sup> Both patient groups had significantly slower RTs and MTs than age matched normal subjects, both were able to use the S-R invariance to preprogramme the response in SRT and use advance information in precued CRT tasks to speed up their RTs relative to uncued CRT. However, both groups showed abnormal interval effects. Patients with Parkinson's disease required a longer S1-S2 interval (3200 ms) to speed up fully cued CRTs to the level of SRT whereas elderly normal subjects did so with an S1-S2 interval of 800 ms.<sup>15</sup> In the present study, instability of attentional set in schizophrenia was associated with equivalent RTs for the fully cued CRT and SRT for the 200 ms and 1600 ms S1-S2 interval but not the 800 or 3200 ms S1-S2 intervals.

#### DEFICITS IN VOLITIONAL PROCESSES IN SCHIZOPHRENIA

The extent to which actions are volitional or reflexive differ on a continuum from the completely automatic and reflexive such as the knee jerk, to the fully internally driven such as spontaneous actions. Most of our daily actions rest somewhere in between. This is also true of the various RT tasks used in the present study, which differed in the degree of volitional control required for selection, preparation, and initiation of a response. The uncued CRT task was probably the least demanding of volitional control. For this reason, the patients with schizophrenia showed no significant differences in uncued CRTs relative to the normal subjects. The SRT task would probably be placed next on a continuum of degree of volitional control required. The optional but internally driven preprogramming in the SRT task is dependent on an act of "will", but as the stimulus-response pairing never varies, the subject preprogrammes the same response on each trial. There was evidence that the patients with schizophrenia were engaging in this.

Finally, in the fully precued CRT, as the imperative stimulus repeated the information held in the precue, preprogramming was also optional and volitional and the subject could simply wait for the imperative stimulus before programming the response similar to uncued CRT. However, in the fully cued CRT although the exact response is known before presentation of the imperative stimulus, the subject must preprogramme a *different* response for each trial. Thus a higher degree of volitional control is required relative to SRT, where given the S-R invariance, the same response is preprogrammed across trials in a block.

Performance of SRT tasks concurrently with a second attention demanding task under dual task conditions, which introduces a capacity load and requires greater volitional control, has been shown to be particularly detrimental to the performance of patients with schizophrenia.<sup>24</sup> In general, evidence suggests that patients with schizophrenia are particularly slowed by increases in task complexity in CRT tasks.<sup>28-32</sup> For example, in a review of the literature on information processing in schizophrenia, Hemsley (D R Hemsley, unpublished PhD thesis 1976) concluded that CRT tasks involving low S-R compatibility are more sensitive to deficits in schizophrenia.<sup>28-33</sup> There is some suggestion from the present results that in schizophrenia RT deficits become more evident as tasks require greater volitional control. As noted above, compared with SRT where the *same* response is preprogrammed across all trials, in fully cued CRT, a *different* response has to be preprogrammed on each trial, hence requiring greater allocation of attention and volitional control. It was precisely on the fully cued CRT condition that the patients with schizophrenia showed unusual and inconsistent interval effects suggesting instability of attentional set. These unusual interval effects are reminiscent of the cross over effect, which has been replicated in schizophrenia in numerous studies. The cross over effect has also been interpreted as reflecting an impaired ability to maintain attentional set.<sup>27</sup> Such instability of attentional set may contribute to other deficits found in schizophrenia such as increased perseveration on the Wisconsin card sorting test<sup>34</sup> or the modality shift effect.<sup>35</sup>

Therefore, the present results suggest that ordinarily, the patients with schizophrenia do not have any major deficits in preprogramming of responses in an SRT or a fully cued CRT task. However, in the second task, in which the volitional demands of preprogramming are higher as a different response has to be prepared on each trial, patients show some unusual and inconsistent interval effects suggesting instability of attentional set. In the present study, it was not possible to differentiate subgroups of patients with predominance of negative signs or positive symptoms. It is possible that future studies using RT tasks requiring greater volitional control (for example, with high stimulus-response incompatibility requiring volitional S-R decoding before response selection) and a sample of patients

with schizophrenia and predominance of negative signs may show greater deficits in willed action.

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