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Saccadic and attentional abnormalities in patients with schizophrenia

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ABSTRACT

Background. Abnormal performance on the antisaccade task suggests that patients with schizophrenia have difficulty with the inhibition of reflexive attentional shifts. The aim of the study was to investigate whether deficits in the inhibition of reflexive attentional shifts were specific to the oculomotor modality or whether they could also occur when attentional shifts were made without eye movements (e.g. covert attentional shifts).

Methods. Fifteen medicated patients with chronic schizophrenia and 15 matched controls performed the antisaccade task and the covert orientating task (COVAT) where the probability of targets appearing at the same location of a peripheral cue was varied so that voluntary and reflexive orientating systems had the same goal (80% probability of target and cued condition) or opposite goals (20% probability of target at cued location). A condition where only reflexive orientating was initiated was also included (50% probability of target at cued location). For each of these conditions the stimulus onset asynchrony (SOA) varied between 150 and 350 ms.

Results. Patients with schizophrenia showed normal latency and accuracy for visually guided saccades but increased error rates and latency on the antisaccade task. For the COVAT, patients with schizophrenia were unable to use voluntary orientating strategies to inhibit reflexive shifts of covert attention. On conditions where only reflexive orientating was required or when the goals of the reflexive and voluntary orientating systems were the same, patients with schizophrenia showed normal performance.

Conclusions. These results suggest the reflexive orientating mode is normal in patients with chronic schizophrenia. However, these patients have a reduced ability to utilize the voluntary orientating mode to control or inhibit reflexive orientating. This impairment of voluntary control is evident for both overt and covert attentional shifts.

INTRODUCTION

Ocular motor studies show that patients with schizophrenia have great difficulty performing the antisaccade task. Antisaccades are eye movements deliberately made in the direction opposite to that of a sudden onset peripheral target. To perform the antisaccade task, subjects must suppress or inhibit a reflexive saccade toward the target, but attend to and use the target's visual information to move their eyes to a symmetrical location in the contralateral visual field (Hallet, 1978; Currie *et al.* 1991). Compared with matched controls, patients with schizophrenia make more incorrect reflexive glances toward the peripheral targets (increased error rate) and when correct antisaccades are made, the latency of these saccades is increased significantly. These abnormalities have been

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reported in both the acute and chronic stages of the illness and have generally been interpreted as increased distractability arising from the dysfunction of inhibitory processes associated with the prefrontal cortices (PFC) (Goldman-Rakic, 1987; Fukushima *et al.* 1988, 1990, 1994; Crawford *et al.* 1995; Henderson *et al.* 1996; Maruff *et al.* 1996). This inference is based on the finding that patients with focal lesions of the PFC also show increased error rates when performing the antisaccade task (Guitton *et al.* 1985; Goldman-Rakic, 1987; Pierrot-Deseilligny *et al.* 1995). Goldman-Rakic (1987) has proposed that antisaccade errors reflect an inability to utilize working memory in order to guide saccades away from compelling visual stimuli. Fletcher & Sharpe (1986) described the inability to inhibit reflexive saccades during the antisaccade task as a visual grasp reflex. However, we have proposed that deficits on the antisaccade task may be described more succinctly within current models of visual attention as an impairment in the ability to use voluntary strategies to inhibit reflexive attentional shifts. This is most evident when the goals of the voluntary and reflexive processes are opposite (Allport, 1992; Rafal & Henik, 1994; Maruff & Currie, 1995; Danckert *et al.* 1998).

Visual spatial attention can also be directed to peripheral targets in the absence of eye movements and this can be measured using the covert orientating of visual attention task (COVAT; Posner, 1980). The COVAT requires that subjects fix their eyes in the centre of the visual field and respond manually to the appearance of a target at a peripheral location in either the left or right visual field. Before the target appears, a spatial cue consisting of a transient luminance increase is presented around one of the peripheral locations. The target may appear at the cued location or at the location contralateral to the cue in the opposite hemifield (uncued location) with equal probability. Spatial cues consisting of transient luminance increases attract the focus of attention reflexively (Yantis & Jonides, 1990; Folk *et al.* 1992; Rafal & Henik, 1994). Therefore, targets are detected more rapidly when they appear at the cued location compared to when they appear at an uncued location in the opposite visual field (Posner *et al.* 1988; Rafal & Henik, 1994). The difference in reaction time (RT) to targets appearing at the cued and uncued locations has been termed the cue effect size and is inferred to represent the additional cognitive operations required when targets appear at the uncued location (Posner & Petersen, 1990; Bowman *et al.* 1993; Maruff & Currie, 1995; Maruff *et al.* 1996). For example, when a target appears in the opposite location to the cue, attention must be disengaged from the cue, moved to the target location and engaged on the target before a manual response can be made. No such operations are required when the target appears at the location where the cue has attracted attention (Posner *et al.* 1987; Rafal & Henik, 1994).

Recently, we have observed that covert visual attention can also be directed away from sudden onset visual cues in a manner similar to the way in which saccades are directed away from peripheral targets during the antisaccade task (Maruff & Currie, 1995; Maruff *et al.* 1996; Danckert & Maruff, 1997; Danckert *et al.* 1998). To measure covert attentional shifts away from sudden onset stimuli, the COVAT was modified so that targets appeared at the uncued location on 80% of trials (i.e. targets appeared at the cued location on only 20% of trials). Under these conditions, normal subjects showed faster RTs to targets appearing at the uncued location compared to the cued location. This reversal in cue effect size suggests that subjects could utilize the probability information contained in the spatial cues to direct attention away from peripheral cues. That is, subjects made use of voluntary strategies to inhibit reflexive attentional shifts (Maruff & Currie, 1995; Danckert *et al.* 1998).

Shifts of attention away from transient onset peripheral targets on the antisaccade task and the COVAT with an 80% probability are similar. On both tasks, subjects must attend to, and utilize, information from transient onset peripheral stimuli to direct an attentional shift towards the contralateral visual field. At the same time they must inhibit reflexive responses towards the peripheral stimulus. Therefore, normal performance on either task may reflect the function of common neurocognitive networks (e.g. Posner & Petersen, 1990; Corbetta *et al.* 1993; Posner & Dehaene, 1994). Disruption to these neurocognitive networks should give rise to abnormal performance on both tasks. Recent research has shown that patients with

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Alzheimer's disease (AD) who show abnormal antisaccade performance also have great difficulty inhibiting reflexive shifts of covert attention (Maruff & Currie, 1995; Danckert *et al*. 1998). If antisaccade abnormalities reflect a general impairment in the voluntary processes necessary to inhibit reflexive attentional shifts, then patients with chronic schizophrenia who exhibit abnormal antisaccadic error rates should also have difficulty inhibiting reflexive covert attentional responses when performing the COVAT with an 80% probability that targets would appear at the uncued location. Therefore, the aim of the current study was to investigate the ability of patients with schizophrenia to inhibit reflexive shifts of attention when such shifts were to be made overtly (with saccades) or covertly (inferred from the pattern of RTs on the COVAT). We hypothesized that patients with schizophrenia who showed impairments in the inability to inhibit saccades on the antisaccade task would also have difficulty inhibiting covert attentional responses when targets were unlikely to appear at the cued location.

METHOD

Subjects

Fifteen patients who fulfilled the Diagnostic and Statistical Manual, Third Edition-Revised (DSM-III-R) (Spitzer *et al*. 1984; American Psychiatric Association, 1986) criteria for schizophrenia were recruited from in-patients in a rehabilitation ward at a major metropolitan psychiatric hospital. Demographic details of the schizophrenia group are presented in Table 1. All subjects in the schizophrenia group were receiving antipsychotic medication. The control subjects were recruited from among auxiliary staff at the research unit and from normal volunteers recruited from the community. There was no difference between groups for mean age ($t(28) = 0{\cdot}7$, $P = 0{\cdot}4$), mean National Adult Reading Test (NART, Nelson *et al*. 1982) estimated pre-morbid IQ ($t(28) = 0{\cdot}6$; $P = 0{\cdot}4$) or in the proportion of male and female subjects. Subjects with a past history of, or coexisting, neurological diseases including head injury, alcohol or drug abuse were excluded. No subject with schizophrenia had evidence of focal brain abnormality on head computerized tomography (CT) scan. Control subjects with a personal or family history of past psychiatric illness were excluded from the study. All subjects gave informed consent and the research protocol was approved by the institutional research and ethics committees.

Apparatus

Eye movement recording

Eye movements were recorded using high resolution infrared oculography (IRIS, Skalar), with the head stabilized in a chin rest. Subjects were seated 1 m from a screen onto which a laser target was projected, computer controlled by X–Y mirror galvanometers (General Scanning, MA). Eye and target position signals were recorded at 1 kHz and stored for off-line analysis. Eye position was differentiated using a computer based algorithm to obtain eye velocity. The recording and scoring of eye movements have been described in greater detail elsewhere (Currie *et al*. 1991; Maruff *et al*. 1996).

Forty, visually guided reflexive saccades were generated by asking subjects to follow the laser target moving horizontally with steps of 500 ms duration and unpredictable direction and amplitude (maximum $\pm 15°$), with a random interstimulus time interval of 1400–2400 ms. Measurements were made of the latency and accuracy of initial saccades to a target step. Hypometric initial saccades were defined as those with an amplitude of less than 85% of the corresponding target step, with one, two or more corrective saccades subsequently required to reach the target.

Forty volitional horizontal antisaccades were generated by asking the patients to fixate on a central green light-emitting diode which was then extinguished simultaneously with the appearance of a peripheral red target positioned either 7·5, 10 or 15° to the left or right of the central fixation point. Subjects were instructed not to look at the peripheral red target, but to look immediately at an imagined point at equal distance on the opposite side of the centre and to hold their gaze there until returning to central fixation with the reappearance of the green central target (3·5 s). Displacement and timing (2·0–2·5 s after fixation) of the appearance of the peripheral red target was random. A correct antisaccade response was an initial eye movement away from the target to the side opposite

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Table 1. *Demographic data for patients with schizophrenia and control group*

Subject	Sex	Age	Est. IQ	Age at onset	Medication (mg per day)	Reality distort.	Disorg.	P/motor Poverty	Antisaccade error rate (%)	20% TAC cue effect
1	M	25	100	18	Clozapine 450, Prozac 20	8	3	8	20	11
2	M	41	97	21	Stelazine 40, Melleril, 200	3	8	0	10	22
3	F	34	112	23	Haloperidol 10	3	4	6	40	48
4	M	27	114	17	Clozapine 300	0	1	3	35	26
5	M	38	102	24	Clozapine 500	8	0	4	75	17
6	M	45	95	25	Remoxipride 600	6	0	9	05	12
7	M	30	112	26	Seroquel 500	8	2	7	30	11
8	M	37	106	22	Risperidone 8	3	2	5	15	−1
9	M	33	103	15	Stelazine 30	3	2	4	30	15
10	M	30	—	19	Clozapine 400	1	3	2	10	30
11	F	33	102	18	Fluphenazine 5, Clozapine 400	2	0	3	70	54
12	M	25	113	24	Fluphenazine 25	0	0	3	25	38
13	M	42	120	19	Clozapine 300	6	5	9	50	44
14	M	21	105	18	Pimozide 16	2	0	4	65	40
15	F	39	103	22	Clozapine 500	1	0	6	45	22
Summary										
Schiz.	12M/3F	33·3 (7·0)	106 (7·7)	20·7 (3·3)		3*	2*	4*	30*	24·9 (17·1)
Control	12M/3F	31·1 (8·3)	109·1 (13·2)	—	—	— —	— —	— —	5*	−23·2 (19·4)

Est. IQ, IQ estimated from the National Adult Reading Test, clinical symptom levels calculated from Manchester Scale (Krawieka *et al.* 1997); reality distort., reality distortion; disorg. disorganization; p/motor poverty, psychomotor poverty. Antisaccade error rate measured as a percentage of total trials completed; 20% TAC cue effect sizes measured in ms; *, median otherwise all values are means with standard deviation in parentheses.

the peripheral red target. Any initial reflexive eye movement towards the target was recorded as incorrect, even if a subsequent correction to the opposite side was made. Trials that involved blink, head movement or anticipatory artefact were rejected. The latency for correct saccades was recorded and a percentage of incorrect responses (error rate %) was calculated.

The covert orientating task (*COVAT*)

The covert orientating of visual attention task (COVAT) was conducted in the ocular motor laboratory and presented on a computer monitor located 35 cm from the subject and controlled by an IBM compatible computer with 1 ms timing for control of stimulus displaying and recording of RTs. A central red fixation point subtending 0·2° of visual angle was flanked by two peripheral green circles that subtended 2° of visual angle and were located 8° to the left and right of the fixation point on the horizontal meridian. The fixation point and the two peripheral circles remained visible throughout an experimental session and were presented at a luminance of 0·01 cd/m^2. The target for the task was a 0·2° red spot that appeared at the centre of either of the peripheral circles. Spatial cues for the appearance of a target consisted of a doubling of the luminance of one of the peripheral circles and remained present until the subject responded to the target. The target could appear at either the same location as the spatial cue (cued location) or at the mirror symmetric location in the contralateral visual field (uncued location). Subjects performed three COVAT tasks each consisting of 240 trials of which 220 were spatially cued. The three tasks differed according to the probability with which the peripheral cue accurately predicted the target would appear at the cued location. For the 50% probability condition the target would appear at the cued and uncued location with equal probability (50% TAC). For the 80% probability condition, the target would appear at the cued location on 80% of trials (and at the uncued location on the remaining 20% of cued trials; 80% TAC). For the 20% probability condition, the target would appear at the cued location on 20% of trials (and at the uncued location on the remaining 80% of cued trials; 20% TAC). The remaining trials were catch trials where the cue appeared but no target followed. These 20 trials were randomly interspersed in a block of trials to minimize anticipatory responding. For all three COVAT conditions, targets appeared pseudorandomly in

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Table 2. *Group mean performance on the saccade and antisaccade tasks*

	Control	Schizophrenia	*t*	*P*
Saccades				
Latency (S.E.)	212·4 (10·1)	232·5 (11·2)	1·3	NS
Gain (S.E.)	94 (3·2)	90 (6·5)	1·2	NS
Antisaccades				
Latency (S.E.)	397·4 (20·1)	450·1 (21·1)	6·5	< 0·001
Gain (S.E.)	93 (4·9)	73 (7·9)	1·7	< 0·01
% Error rate (range)*	5 (0–20)	30 (5–75)	8·5	< 0·001

* Error rates were compared between median % antisaccade error rates using Mann–Whitney *U* test. Latency and gain calculated only for correct antisaccades.

the left visual field (LVF) or right visual field (RVF) and the stimulus onset asynchrony (SOA) varied pseudorandomly between 150 and 350 ms SOA. Subjects were instructed to look at the central fixation point and to press the response button whenever they detected a red target in either of the peripheral circles. Fixation was monitored using infrared oculography. Trials on which breaks of fixation occurred were excluded. Before each experimental condition, subjects were informed about the target at cue probability and 20 practice trials were administered. A rest period of 2–3 min was given after every 50 trials in a single block. The inter-trial interval varied randomly between 1060–1130 ms. All of the subjects completed the three COVAT conditions in one testing session and the order of administration of the three conditions was randomized between subjects.

Data analysis

Eye movements

Horizontal eye and target position signals were digitized at 1 kHz and computer stored for off-line analysis. Saccades were identified by a software algorithm using criteria derived from eye movement velocity (Currie *et al.* 1991; Maruff *et al.* 1995). As in previous studies of saccades to remembered targets we measured the latency of first saccades only (Smit *et al.* 1987; Pierrot-Deseilligny *et al.* 1991). The following trials were rejected: no saccade made in response to a target appearance, saccades that were disrupted by a blink, head movement or other artefact, eye movements that began with a saccade in the direction opposite to that of the target or a saccade initiated before the presentation of the peripheral target (anticipatory saccades), saccade to target made before offset of central fixation. For visually-guided saccades, there was no significant difference in the median percentage of excluded trials between control (2·5%, range = 0–5%) and schizophrenia groups (2·5%, range = 0–7·5%; Mann–Whitney *U* (MW*U*) = 128; $P = 0{\cdot}1$). However, for antisaccades, the median percentage of trials excluded was greater in the schizophrenia group (7·5%, range = 0–12·5%) than in the controls (2·5%, range = 0–7·5%; MW*U* = 98; $P < 0{\cdot}05$). Despite this difference, the number of saccades for each subject was sufficient to provide reliable estimates of antisaccade latency. The equivalent standard errors of the mean for antisaccade latency between the two groups is shown in Table 2. The latency of saccades was calculated as the time elapsed between the onset of the peripheral target and the onset of the initial saccade made to locate the target. The latency of antisaccades was calculated as the time elapsed between the onset of the peripheral target and the onset of the initial saccade to the mirror symmetric location.

COVAT performance

For each subject, RTs from the three COVAT conditions were collapsed into single distributions. These distributions were inspected for anticipatory and abnormally slow responses. Anticipatory responses were defined as those with RTs < 100 ms. Abnormally slow responses were defined as RTs whose value was greater than the 99th percentile of the individual subject's distribution. Trials excluded using this method did not exceed 4·7% for any subject. These trials were excluded from further analysis. Differences in general RT between groups were not the focus of the current study. To compare COVAT performance between groups a cue

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effect size was calculated for each subject under each target at cue probability condition at both SOAs using the formula:
cue effect size = RT to targets appearing contralateral to the cue minus RT to targets appearing at the cue.

According to this equation, a RT advantage for targets appearing at the cued location would result in positive cue effect size. Conversely, a RT advantage for targets appearing contralateral to the cued location will result in a negative cue effect size. Cue effect sizes have been shown to be valid and reliable indices of the speed with which covert attention can be directed following a spatial cue (Robinson & Kertzman, 1990; Maruff & Currie, 1995; Maruff *et al*. 1996; Danckert & Maruff, 1997). Cue effect sizes were then submitted to a 2 (group) × 3 (probability) × 2 (SOA) analysis of variance with repeated measures on the probability and SOA factors.

RESULTS

There was no significant difference in the latency or accuracy of saccades toward targets between the schizophrenia and control groups. On the antisaccade task, patients with schizophrenia made significantly more incorrect saccades toward the target (antisaccade errors) than controls. The mean latency of correct antisaccadic eye movements was also slower in the schizophrenia group than in controls and the mean gain of antisaccades was also less than found for controls (see Table 2).

For the COVAT performance, ANOVA indicated a significant interaction between group, SOA and TAC probability condition ($F(2, 27) = 76{\cdot}3$; $P < 0{\cdot}0001$). This interaction is shown in Fig. 1 and was investigated with a series of Group × SOA ANOVAs for each of the TAC probability conditions. For the 80% TAC probability condition, there was a significant effect for SOA ($F(1, 28) = 5{\cdot}9$; $P = 0{\cdot}01$) but not for group ($F < 1$) and no Group × SOA interaction ($F < 1$). Fig. 1*a* shows that cue effect sizes were significantly smaller for the 350 ms SOA than for the 150 ms SOA but that there were no group differences in cue effect size at either SOA. For the 50% TAC probability condition there was also a significant effect for SOA ($F(1, 28) = 10{\cdot}5$; $P < 0{\cdot}001$) but not for Group ($F < 1$) and no Group × SOA interaction ($F(1, 28) = 2{\cdot}1$; $P = 0{\cdot}1$). Fig. 1*b* shows that, for both groups, cue effect sizes were positive at the 150 ms SOA and negative at the 350 ms SOA. At the 150 ms SOA, cue effect sizes were significantly smaller in the 50% TAC probability condition compared with the 80% TAC probability condition ($F(1, 28) = 6{\cdot}3$; $P = 0{\cdot}01$). For the 20% TAC probability condition (i.e. targets appeared contralateral to the cued location on 80% of trials), there was a significant effect for Group ($F(1, 28) = 45{\cdot}7$; $P < 0{\cdot}0001$) and for SOA ($F(1, 28) = 65{\cdot}3$; $P < 0{\cdot}0001$) and a significant Group × SOA interaction ($F(1, 28) = 15{\cdot}7$; $P < 0{\cdot}001$). Fig. 1*c* shows that the interaction arose because the control group showed negative cue effect sizes. This negative cue effect size indicates that control subjects had a RT

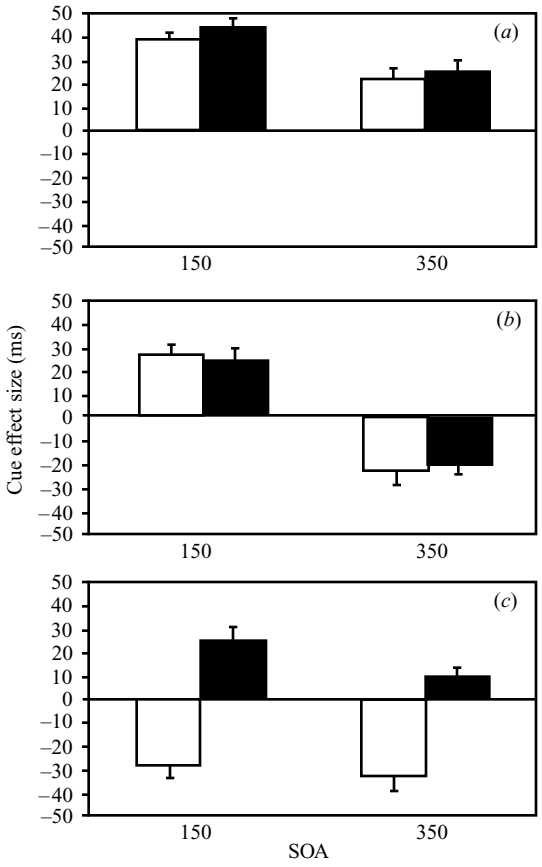


FIG. 1. Mean (+S.E.) cue effect sizes for both control subjects (□) and patients with schizophrenia (■) in each COVAT task. (*a*) = 80% TAC probability COVAT; (*b*) = 50% TAC probability COVAT; (*c*) = 20% TAC probability COVAT.

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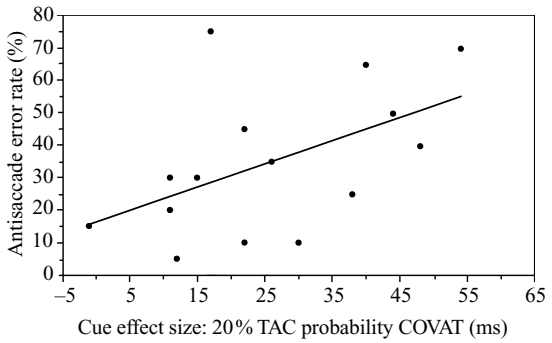


FIG. 2. Scatterplot of correlation between cue effect size under the 20% target at cue probability condition and antisaccade error rate in the schizophrenia group.

advantage for targets appearing contralateral to the cued location at both the 150 and 350 ms SOA. In contrast to this, cue effect sizes in the schizophrenia group were positive at both SOAs, suggesting a RT advantage for targets appearing at the cued location even though this was the more unlikely event.

To investigate the relationship between performance on the 20% TAC probability condition and performance on the antisaccade task in the schizophrenia group at the 150 ms SOA, cue effect sizes were correlated with correct antisaccade latency and with the number of antisaccade errors using Spearman's rho (ρ_s) There was no correlation between antisaccade latency and cue effect sizes in the 20% TAC COVAT, however, there was a moderate correlation between cue effect size and percentage of antisaccade errors ($\rho_s = 0{\cdot}51$, $P = 0{\cdot}02$) (Fig. 2). Finally, there were no correlations between amount of antipsychotic medication (converted to chlorpromazine equivalents) or the level of symptoms and the 20% TAC probability COVAT cue effect size or the percentage of antisaccade errors.

DISCUSSION

The current results indicate that patients with schizophrenia have an impaired ability to inhibit reflexive shifts of attention whether these shifts are overt or covert. The ability to inhibit overt reflexive shifts of attention was measured using the antisaccade task. On this task, patients with schizophrenia made significantly more errors (reflexive glances toward the target) than controls. Even when correct antisaccades were made, the latency of these saccades was increased and the gain decreased when compared with controls. The ability to inhibit covert reflexive shifts of attention was measured using a COVAT where it was highly probable that targets would appear in the contralateral location to the cue (i.e. 20% TAC COVAT, see Fig. 1*c*). Normal subjects could use probability information to direct attention away from transient onset peripheral cues. However, patients with schizophrenia could not direct attention away from peripheral cues despite the high probability that targets would not appear at the cued location. There was a moderate correlation between the ability to inhibit reflexive shifts of attention in both the covert and overt modalities suggesting that the performance deficits on the two tasks reflected disruption to common underlying processes (Fig. 2).

The normal cue effect sizes found for the schizophrenia group when non-predictive peripheral cues initiated covert shifts of attention (50% TAC probability condition) suggest that the reflexive orientating of attention is normal in chronic schizophrenia (Fig. 1*a*, Yantis & Jonides, 1990; Folk *et al.* 1992; Rafal & Henik, 1994). Importantly, this normal performance occurred for both the facilitation (indicated by the positive cue effect size at the 150 ms SOA) and inhibition of return (IOR, indicated by the negative cue effect size at the 350 ms SOA) components of reflexive orientating. Recently, we have suggested that facilitation arises because peripheral cues at short SOAs initiate an attentional shift. However, at longer SOAs, IOR arises because peripheral cues induce a motor bias so that responses to targets appearing at cued locations become slower than those made to targets appearing in novel locations (Maruff *et al.* 1998). The addition of information indicating that the target was likely to appear at the cued location to peripheral cues increased the effectiveness with which peripheral cues attracted attention. Compared to the 50% TAC probability condition, the magnitude of cue effect sizes increased for both SOAs in both groups under the 80% TAC condition. This suggests that voluntary and reflexive processes have an additive effect on the speed of attentional shifts and that voluntary strategies can overcome IOR at long SOAs.

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The most important group difference found for covert orientating occurred for the condition with a high probability that targets would appear in the uncued location (20% TAC probability condition; Fig. 1*c*). Under this condition, in normal subjects, detection was faster when targets appeared in the uncued location. This suggests that although the peripheral cue attracted the attentional focus automatically, subjects were able to disengage attention from that cue and redirect it to the opposite visual field before the target appeared. Thus, subjects could use a voluntary strategy to inhibit orientating reflexively towards the cue (Maruff & Currie, 1995; Danckert & Maruff, 1997). However, the positive cue effect size found in the schizophrenia group under the 20% TAC probability condition suggests that patients with schizophrenia continued to orientate to the peripheral cue despite the high probability that the target would appear in the opposite location. That is, they could not use voluntary attentional processes to shift their attention away from the peripheral cue once it appeared. In addition, there was a moderate correlation between the percentage of antisaccade errors and the magnitude of the cue effect size in the 20% TAC COVAT (i.e. in which there was an 80% probability that targets would appear in the uncued location). This correlation indicates that patients with schizophrenia who showed high antisaccade error rates also showed large and positive cue effect sizes in the 20% TAC probability COVAT (see Table 1).

The current interpretation of the results rests on the assumption that patients with schizophrenia were able to learn the different target at cue probability information when it was added to peripheral cues. However, they were unable to make use of this information to direct attention voluntarily away from peripheral cues even though it was highly probable that the target would appear at the uncued location. Therefore, it is possible that the performance deficit in the schizophrenia group reflected a difficulty in using the implicitly learned probability information to guide the orientating behaviour rather than any specific deficit of voluntary control. Three aspects of COVAT performance in schizophrenia groups argue against this possibility. First, there was a significant increase in the cue effect size when information indicating that the target was highly likely to appear at the cued location was added to peripheral cues (compare cue effect sizes in the 50% to 80% TAC probability conditions). This increase was equivalent in both groups indicating that the patients with schizophrenia were as effective as controls in learning, and utilizing, target at cue probability information added to peripheral cues. Secondly, when targets were more likely to appear in the opposite location to the cue (20% TAC probability condition), the positive cue effect sizes at the 350 ms SOA were reduced when compared with those at the 150 ms SOA (Fig. 1*c*). This suggests that the probability information did interfere with the reflexive orientating of attention to peripheral cues provided there was more time between cue and target. Thirdly, in a previous experiment we have observed that patients with schizophrenia were unable to inhibit orientating to peripheral cues even when there was a 100% probability that the target would not appear at the cued location (Maruff *et al.* 1996). Under these conditions, subjects were not required to learn any probability information from the repeated pairing of cue and target in order to guide attentional shifts away from peripheral cues. Therefore, when taken together, these results suggest strongly that the positive cue effect sizes found for the 20% TAC probability condition reflect a deficit in the ability to direct attention away from sudden luminance onsets in the peripheral visual field.

As patients with schizophrenia were able to use probability information, they would have expected that under the 20% TAC probability condition, the target was unlikely to appear where their attentional focus was aligned. However, their attentional focus was bound to the cue until the target appeared. Therefore, RTs to targets that appeared at the cued location remained significantly faster than RTs to targets appearing at the contralateral location to the cue, even though the probability of targets appearing at the cued location was very low. Once the target appeared, the attentional shift towards the contralateral location could begin. The extra time required to complete the cognitive operations in this shift from cue to target resulted in the slower RTs for targets appearing at the uncued location (i.e. positive cue effect size under the 20% target at cue probability con-

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dition). This dependence on the appearance of the target to initiate the covert attentional shift can, therefore, also be viewed as reflecting an excessive dependence on external cues and an inability to use representational information to shift the attentional focus voluntarily from the initial cue to the contralateral visual field.

The similarity between the inhibitory deficits found on the antisaccade task and the 20% probability COVAT suggests that they arise from the same disruption to neurocognitive networks in schizophrenia. The impairment in performance of antisaccades in the schizophrenia group is consistent with previous investigations of medicated patients with schizophrenia (Goldman-Rakic, 1987; Fukushima *et al.* 1988, 1990*a*, *b*; Rosse *et al.* 1993; Crawford *et al.* 1995; Maruff *et al.* 1996). These studies have inferred that abnormal antisaccade performance reflects a dysfunction of inhibitory ocular motor areas in the PFC. This interpretation is based on the finding that patients with lesions of the frontal cortex also have great difficulty performing the antisaccade task (Guiton *et al.* 1985; Pierrot-Deseilligny *et al.* 1995). Consistent with this inference, studies of schizophrenia have found that the severity of antisaccade abnormalities is correlated with frontal lobe atrophy measured from CT (Fukushima *et al.* 1990*a*) as well as with poor performance on tests of executive function also hypothesised to depend on frontal lobe function (Rosse *et al.* 1993). However, the ability to make antisaccades depends on an integrated network of both cortical and subcortical structures. For example, single neuronal recording studies in alert primates (Funahashi *et al.* 1993; Amador *et al.* 1995), ocular motor studies of patients with focal brain lesions or neurodegenerative diseases (Guitton *et al.* 1985; Currie *et al.* 1991; Kitagawa *et al.* 1994) as well as positron emission tomography studies of normal subjects performing the antisaccade task (Kertzman *et al.* 1993; O'Driscoll *et al.* 1995), all suggest that the ability to make antisaccades depends on the integrity of a distributed network of cortical and subcortical brain structures including the frontal eye fields, supplementary motor area, thalamus and putamen, in addition to the PFC. Therefore, on the basis of the current behavioural data, it is not possible to exclude these other brain areas from involvement in the aetiology of abnormal antisaccade performance in patients with schizophrenia.

Neuropsychological studies of covert orientating suggest that IOR is disrupted following damage to the superior colliculus (Rafal & Henik, 1994). In the current study, patients with schizophrenia showed normal IOR at the 350 ms SOA in the COVAT with non-predictive peripheral cues (50% TAC probability condition; see Fig. 1*b*). This suggests that attentional processes associated with the superior colliculus were unaffected in medicated patients with schizophrenia. Previous research has also found that lesions of the parietal lobes interfere with the ability to disengage attention following invalid cues leading to increased cue effect sizes (Posner & Petersen, 1990; Maruff *et al.* 1995). The normal cue effect sizes observed for the 50% and 80% probability conditions suggest that the parietal lobe processes necessary for the disengagement of attention were unaffected in the patients with schizophrenia. Therefore, we postulate that in the current medicated chronic schizophrenia group, abnormal antisaccade error rates and abnormal performance on the COVAT where targets were highly likely to appear in the opposite visual field are overt and covert manifestations of a general attentional grasp reflex. This grasp reflex may arise from disruption to frontal lobe attentional areas. The results of a recent study using positron emission tomography (PET) support the existence of a frontal lobe attentional area (Corbetta *et al.* 1993). This study reported that a region of the superior frontal cortex was found to be active when covert attention was directed away from peripheral stimuli to the contralateral visual field in order to detect targets. This activation was not found when attention was maintained at the centre of gaze and central stimuli were detected. One interpretation of this frontal activation was that it reflected the use of attended peripheral visual information to execute an attentional shift in the opposite direction for a motor response. Such an interpretation is consistent with the current hypothesis that disruption to frontal lobe attentional areas in schizophrenia results in a general inability to shift attention voluntarily away from compelling peripheral visual stimuli.

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