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Reliability of smooth pursuit, fixation, and saccadic eye movements

ULRICH ETTINGER,[a,b] VEENA KUMARI,[a,c] TREVOR J. CRAWFORD,[d] ROBERT E. DAVIS,[b] TONMOY SHARMA,[e] AND PHILIP J. CORR[b]

[a]Section of Cognitive Psychopharmacology, Division of Psychological Medicine, Institute of Psychiatry, University of London, UK
[b]Department of Psychology, Goldsmiths College, University of London, UK
[c]Department of Psychology, Institute of Psychiatry, University of London, UK
[d]Mental Health and Neural Systems Research Unit, Psychology Department, Lancaster University, UK
[e]Clinical Neuroscience Research Centre, Dartford, UK

Abstract

The present study investigated the reliability and susceptibility to practice effects of oculomotor tasks. Smooth pursuit, fixation, antisaccade, and prosaccade tasks were administered to 31 healthy participants to assess internal consistency (Cronbach's alpha) and within-session practice effects. Twenty-one of these participants were retested after an average interval of 57.86 days to assess temporal stability and between-session practice effects. Internal consistencies were high for most measures, with few within-session performance changes. Test–retest reliabilities of most measures were good. Between-session practice effects were most consistently observed on the antisaccade task, indicated by reduced error rate and improved spatial accuracy at retest. Magnitude of improvement on these measures was related to performance, indicating that poor performers benefited most from repeated assessment. These findings support the trait nature of oculomotor function and point to the need to take into consideration between-session practice effects on the antisaccade task in longitudinal studies.

Descriptors: Smooth pursuit eye movements, Visual fixation, Antisaccade, Prosaccade, Test–retest reliability, Internal consistency, Practice effects

Smooth pursuit eye movement (SPEM) and antisaccade deficits have been proposed as endophenotypes in genetic schizophrenia research (Calkins & Iacono, 2000; Clementz, 1998; Holzman, 2000). An endophenotype is a specific behavioral or biological deficit believed to be a more direct expression of a disease gene than the disease phenotype itself (Leboyer et al., 1998; Ott, 1991). The smooth pursuit task requires participants to follow a slowly moving visual target. Deficits on this task are common among schizophrenia patients and include reduced gain (the ratio of eye over target velocity) and an increased frequency of compensatory and intrusive saccades during pursuit (Calkins & Iacono, 2000; Hutton & Kennard, 1998). The antisaccade task requires the initiation of a rapid eye movement in the opposite direction to a sudden visual target. Antisaccade performance in schizophrenia is principally characterized by an increased error rate, namely, an increased number of reflexive saccades towards the target (Calkins & Iacono, 2000; Clementz, 1998).

The SPEM and antisaccade deficits bear considerable promise as schizophrenia endophenotypes given observations not only in schizophrenia patients but also in other schizophrenia spectrum populations, such as schizotypal individuals and first-degree relatives of schizophrenia patients (Clementz, McDowell, & Zisook, 1994; Crawford et al., 1998; Holzman et al., 1974; Iacono, Moreau, Beiser, Fleming, & Lin, 1992; O'Driscoll, Lenzenweger, & Holzman, 1998) and preliminary evidence of genetic linkage (Arolt et al., 1999; Myles-Worsley et al., 1999).

An important characteristic of a putative endophenotype is its trait, rather than state, nature. Accordingly, a number of studies have investigated the temporal stability of eye movement performance among healthy individuals as well as schizophrenia patients. The consensus from studies of SPEM is that performance is relatively stable in schizophrenia patients and healthy individuals over time intervals ranging from 1 week to 2 years, with correlation coefficients between about 0.5 and 0.9 (Campion et al., 1992; Gooding, Iacono, & Beiser, 1994; Holzman, Proctor, & Hughes, 1973; Iacono & Lykken, 1981; Roy-Byrne, Radant, Wingerson, & Cowley, 1995; Schlenker & Cohen, 1995; Yee, Nuechterlein, & Dawson, 1998).

There is a relatively little research into the temporal stability of saccadic eye movements. Some studies have reported good reliabilities of prosaccade velocity, spatial accuracy, and latency, as well as of amplitude-duration and amplitude-velocity relationships (Iacono & Lykken, 1979; Versino et al., 1993; Wilson, Glue, Ball, & Nutt, 1993). Fewer studies, however, have addressed the antisaccade task. Roy-Byrne et al. (1995) reported nonsignificant

Address reprint requests to: Dr. Ulrich Ettinger, Section of General Psychiatry, Division of Psychological Medicine PO63, Institute of Psychiatry, De Crespigny Park, London SE5 8AF, UK. E-mail: u.ettinger@iop.kcl.ac.uk.

intraclass correlations (ICC) for the key antisaccade measure, namely, the error rate, probably due to the restricted range of scores (the number of errors ranged between 0 and 2) and the small sample size ($N = 8$). Klein and Berg (2001) reported poor reliability of the antisaccade error rate in 20 individuals. Given the proposition that the antisaccade error rate might be a useful schizophrenia endophenotype (Calkins & Iacono, 2000; Clementz, 1998), its temporal stability must first be clarified.

A topic related to the test–retest reliability of eye movement measures concerns practice effects. People generally do not show significant improvements on SPEM measures at retest (Campion et al., 1992; Gooding et al., 1994). On the antisaccade task, however, reductions in error rate between baseline and retest have been observed over a time interval of 1 week (Green, King, & Trimble, 2000; Klein, Fischer, Fischer, & Hartnegg, 2002). Practice effects might have serious implications for longitudinal clinical studies where performance is evaluated over time as a function of changes in clinical or medication status.

A second important reliability criterion is a task's internal consistency (Anastasi & Urbina, 1997). Internal consistency is a measure of the reliability of content sampling, or homogeneity of items (or trials), as well as within-session consistency of performance. Little research has been carried out into the internal consistency of oculomotor performance. Cegalis and Sweeney (1979) reported high consistencies of saccadic frequency and spatial error for different intervals of smooth pursuit tracking. We are aware of no reports of internal consistencies of saccadic variables.

A related issue is that of within-session performance changes. Within-subject changes in performance levels within one test session may be expected due to fatigue or boredom (deterioration) or due to practice (improvement). Given the observation of significant between-session practice effects on the antisaccade task over intervals of several days (Green et al., 2000; Klein et al., 2002), it is important to examine whether performance on this task also improves within a single session. Previous research has pointed to differences in the cognitive processes mediating within- and between-session learning (Hauptmann & Karni, 2002).

The present study had the following aims. First, to investigate the temporal stability of SPEM, fixation, antisaccade, and prosaccade performance in a sample of healthy individuals over a period of 2 months. Given the proposed trait nature of these oculomotor measures, high reliabilities were expected. Second, to assess whether performance levels changed between sessions. Given previous reports, no improvements on SPEM measures, but reductions in antisaccade error rate, over time, were hypothesised. Third, to assess internal consistencies of these tasks using Cronbach's coefficient alpha (Cronbach, 1951). Finally, to examine whether there were any within-session changes in levels of oculomotor performance.

Method

Participants

Thirty-one participants (20 men, 11 women; age range 19–44 years, mean = 27.26, $SD = 6.79$) underwent assessment. Participants were recruited from among staff and students of the University of London. All participants were free of psychiatric disorder by self-report. All participants provided written, informed consent after the study details had been fully explained to them. Departmental ethical permission was granted (Department of Psychology, Goldsmiths College). Twenty-one (15 men, 6 women; age range 19–43 years, mean = 26.33, $SD = 6.37$) of these participants could be recruited for retest. Participants repeated oculomotor assessments with an average test–retest interval of 57.86 days ($SD = 19.04$; range = 38–105 days).

Participants who volunteered for retest did not significantly differ from other participants on sex, $\chi^2 = 1.36$, $p = .24$, age, $F(1, 27) = 2.51$, $p = .13$, or any oculomotor variables, all $F < 4.09$, $p > .05$, with the exception of lower saccadic frequency during fixation, $F(1,27) = 5.73$, $p = .03$.

Eye Movement Tasks

Stimuli were displayed on a 17-in. computer monitor. A white target of circular shape (approximately 0.3° of visual angle) was presented on a black background. Participants sat in a comfortable chair at a distance of 57 cm from the monitor; head movements were minimized using a chin rest. Testing took place in a quiet, darkened room. A three-point calibration task (+12°, 0°, −12°; each stimulus duration = 1,000 ms) was carried out before each task.

Smooth pursuit. A triangular target waveform was used at four velocities (12°/s, 24°/s, 36°/s, and 48°/s). The target was initially placed in the central position (0°) and then moved horizontally to one side until it reached the ±12° location, where it reversed abruptly and moved to the opposite side. The direction of the first ramp was random (right or left). The first ramp (from central location to first eccentric location) was considered practice and was not used in the analysis. A total of 16.5 half-cycles were run at each target velocity and included in the analysis. Participants were instructed to keep their eyes on the target wherever it moved. One participant's SPEM data at 0.25 Hz and a second participant's SPEM data at 0.75 Hz were unusable due to artefacts.

Fixation. The target remained stationary in each of three locations (0°, ±12°). Two peripheral and two central targets were used with durations of 20 s each. Participants were instructed to focus their gaze on the target as accurately as possible. One participant's fixation data were unavailable because of data storage error, and one participant's fixation data were unusable due to artefacts.

Antisaccade. An antisaccade trial began with the target in the central location for a random duration of 1,000–2,000 ms. The target was then abruptly moved to one of four peripheral locations (±6°, ±12°) where it remained for 1,000 ms. Each peripheral location was presented 15 times, resulting in a total of 60 trials. The sequence of peripheral target presentations was random (sampling without replacement). Four practice trials using each target location once were carried out before the experimental trials and could be repeated if necessary. Participants were instructed to look at the target while in the central position and redirect their gaze to the exact mirror image location of the target as soon as it moved to the side.

Prosaccade. The prosaccade task was identical to the antisaccade, except for participants' requirement to follow the target as quickly and accurately as possible.

Eye Movement Recording

Eye movements were recorded using infrared oculography (IRIS model 6500; Skalar Medical BV, Delft, The Netherlands; Reulen et al., 1988) at a sampling frequency of 500 Hz. With the IRIS system, horizontal recordings may be made within a range of $\pm 30^\circ$. The linearity of the system lies within 3% between $\pm 25^\circ$ of horizontal recordings. For convenience, recordings were taken from the left eye only. Eye and target position were logged by the eye-tracker. Signals were converted from analogue to digital by a four-channel analogue-to-digital converter card with 12 bits resolution per channel. Data were saved onto hard disk for further analysis.

Eye Movement Analysis

The purpose-written software package EYEMAP (AMTech GmbH, Weinheim, Germany; e.g., Crawford et al., 1998; Lencer et al., 1999) was used for analysis of eye movement data. Inter- and intrarater reliabilities using EYEMAP in our laboratory are high, ranging from $r = 0.85$ to $r = 0.99$.

Smooth pursuit. SPEM data were smoothed twice using a five-point central averaging filter. Pursuit gain was obtained by dividing eye velocity by target velocity at midcycle steady-state pursuit for each half-cycle; scores were then averaged across half-cycles for each target velocity.

Detection of saccades during pursuit was based on criteria of minimum amplitude (1.5°) and velocity (30°/s). Anticipatory saccades (AS) were defined as saccades in the target direction that took the eye ahead of the target. AS were followed either by slowing or cessation of pursuit. Following Ross, Olincy, and Radant (1999) it was decided to include AS with a small minimum amplitude criterion (1.5°). Catch-up saccades (CUS) were defined as saccades in the target direction that served to reduce position error, that is, to bring the eye closer to the target. CUS always began with the eye behind the target. If a saccade initiated behind the target and ended ahead of it, it was classified as an AS if more than half of the amplitude served to move the eye ahead of the target. If more than half of the amplitude was spent behind the target, that is, reducing position error, the saccade was considered a CUS (Ross, Olincy, Harris, Radant, Adler, et al., 1999). To avoid calibration problems due to subtle head movements, saccades that did not clearly meet criteria for either AS or CUS were discarded. The number of AS and CUS were counted for each velocity and divided by the duration of pursuit, to yield indices of saccadic frequency (*N*/s).

Back-up saccades and square-wave jerks were also counted but occurred infrequently and were omitted from statistical analysis. Previous studies have suggested that these types of saccades do not represent important schizophrenia endophenotypes (Clementz, Sweeney, Hirt, & Haas, 1990; Lencer et al., 1999; Radant & Hommer, 1992).

Fixation. Visual fixation performance was assessed by calculating the frequency of saccades (N/s) based on criteria of minimum amplitude (1.5°) and minimum velocity (30°/s).

Prosaccade. Detection of saccades was based on criteria of minimum amplitude (1.5°), minimum velocity (30°/s), and minimum latency to target (100 ms). Eye-blink trials, which were rare, were excluded. Saccadic latency was defined as the time (in milliseconds) from target appearance to saccade initiation of correct trials.

Two measures of spatial accuracy were employed. First, primary prosaccade gain was calculated as the percentage of saccade amplitude divided by target amplitude multiplied by 100. Gain of a perfectly accurate prosaccade is thus 100%, with gain of less than 100% reflecting a *hypo*metric saccade (undershoot) and gain of more than 100% reflecting a *hyper*metric saccade (overshoot). Primary saccade gain is an established measure of spatial accuracy (Bötzel, Rottach, & Büttner, 1993). A measure that captures hypo- and hypermetric saccades is of interest, as these types of saccadic spatial error have been shown to have different neural correlates (Bötzel et al., 1993; Ettinger et al., 2002). However, the very distinction between hypo- and hypermetric saccades may mask the fact that two different gain scores (e.g., a hypometric saccade of gain = 80% and a hypermetric saccade of gain = 120%) may actually both be equally inaccurate, namely, “off target” (by 20%).

Therefore, to provide a further quantification of spatial accuracy, spatial error was obtained by calculating, for each saccade, the percentage of residual error. Residual error was calculated by subtracting the target amplitude from saccade amplitude and dividing the result by the target amplitude. The absolute value of this term reflects the residual error and was then averaged across all saccades and multiplied by 100. A perfectly accurate saccade thus attracts a spatial error score of 0%; higher scores denote greater spatial error, irrespective of saccadic overshoot or undershoot.

Antisaccade. Antisaccade gain (percentage), spatial error (percentage), and latency (in milliseconds) were calculated as above. Additionally, antisaccade errors were counted when the participant initiated a primary saccade toward the peripheral target; a correct antisaccade trial was counted when the participant performed a primary saccade in the opposite direction to the peripheral target. The error rate reflects the percentage of error trials over the total number of valid trials (excluding invalid trials, e.g., eyeblinks or artefact). A corrective saccade was counted when an error was followed by a saccade in the opposite direction.

Statistical Analysis

All statistical analyses were performed using the Statistical Package for the Social Sciences Version 10 (SPSS Inc., Chicago, IL). The alpha level was set at 0.05. Oculomotor variables were assessed for normality of distributions. A small number of variables were slightly positively (skewness > 1) or negatively (skewness < -1) skewed and were transformed accordingly. Transforming skewed variables did not noticeably affect results; therefore, descriptive statistics as well as results reported below are based on untransformed variables.

Test–retest reliability. Intraclass correlation (ICC) is the appropriate statistical method in reliability analysis (Bartko, 1991) and was, therefore, used to assess temporal stability. Correlations (e.g., Pearson) measure associations between variables by assessing between-subject variance, failing to take account of systematic differences across assessments (or between raters), that is, within-subject variance. Therefore, if participants obtain identical scores on two occasions, both Pearson correlation and ICC will indicate unity, that is, perfect association and agreement, respectively ($r = 1$; ICC = 1). However, if participants' scores systematically differ between occasions, ICC will be a more realistic estimate of agreement, that is, of within-subjects variance. Generally, ICC tend to be somewhat lower than Pearson correlations, and may be considerably lower if within-subjects variance is large.

To provide an estimate of the differences in magnitude between ICC and Pearson correlations, and to allow comparisons with previous studies (Campion et al., 1992; Gooding et al., 1994; Klein & Berg, 2001; Schlenker & Cohen, 1995), both coefficients are reported here.

Another method to estimate reliability, complementing Pearson and ICC, is that suggested by Bland and Altman (1986). These authors proposed the Repeatability Coefficient (RC). RC represents twice the standard deviation of the distribution of difference scores for two assessments. In repeated assessments without systematic effects of repeated exposure, the mean of difference scores will be zero; if repeated assessment is highly reliable, then RC will be small. If differences between two assessments are primarily due to random error of measurement, then the distribution of difference scores is expected to be normal (Gaussian). Therefore, 95% of cases are expected to fall within $\pm 2SD$ of the mean; this is what RC denotes. Bland and Altman suggested plotting the relationship between the difference score and the average score of first and second assessment to inspect whether differences between first and second assessment are systematically related to overall performance.

Between-session effects. To probe for effects of repeated exposure between sessions, repeated measures *t* tests were carried out between pairs of oculomotor variables at baseline and retest. Effect sizes were calculated according to the formula $(\mu_1 - \mu_2)/sd_{\text{diff}}$ where μ_1 = mean of session 1, μ_2 = mean of session 2, and sd_{diff} = standard deviation of the difference scores (Cohen, 1988).

Internal consistency. Internal consistency was assessed using Cronbach's coefficient alpha (Cronbach, 1951). Coefficient alpha is the most appropriate measure of internal consistency for tests with items that depart from a binary response format (e.g., 1 = correct; 0 = incorrect; Anastasi & Urbina, 1997). To compute Cronbach's alpha, subscores for SPEM and saccadic measures were calculated.

Subscores were obtained for segments (time sections) of pursuit and saccadic eye movement recordings. Recordings were divided into four consecutive sections of equal length. For smooth pursuit, gain and frequencies of AS and CUS were obtained for each section at each of the four target velocities. For antisaccade and prosaccade tasks, saccadic metrics were obtained for each section. For visual fixation, internal consistency was calculated for four segments consisting of the two peripheral and two central target presentations.

Within-session effects. To examine whether performance levels changed across consecutive sections within the baseline session, repeated measures analyses of variance (ANOVA) were carried out for each variable, with segment (1, 2, 3, 4) as the within-subject factor. Mauchly's test was considered for each variable to assess assumptions of sphericity. If assumptions of sphericity were violated, the Greenhouse–Geisser epsilon corrections of degrees of freedom were used (Jennings, 1987).

Within-session changes at retest were examined only for variables showing significant between-session changes. This was done to clarify whether the observed between-session changes could be attributed to within-session learning at retest. For this purpose, repeated measures ANOVA with segment (1, 2, 3, 4) as the within-subject factor were carried out.

Results

Participants' average antisaccade correction rate at baseline was high (mean = 99.36%; SD = 2.09), indicating they were willing and able to perform the task (McDowell & Clementz, 1997).

Test–Retest Reliability

Descriptive statistics of oculomotor variables at baseline and retest, Pearson correlations, ICC, and repeatability coefficients are given in Table 1. The reliability of the key antisaccade measure of error rate is depicted in Figure 1. For all measures, Pearson correlations were the same or larger than ICC, with most ICC and Pearson correlations significant. Repeatability coefficients (RC) essentially parallel these correlations. Nonsignificant

Table 1. *Descriptive Statistics of Oculomotor Variables at Baseline and Retest (N = 21), Pearson and Intraclass Correlations (ICC), Repeatability Coefficients (RC), t Tests, and Effect Sizes (ES)*

	Baseline		Retest						
	Mean	*SD*	Mean	*SD*	Pearson	ICC	RC	*t* test	ES
SPEM gain 12°/s	98.60	8.09	96.35	9.28	$r = 0.11, p = .64$	ICC = 0.10, $p > .10$	23.53	$t = 0.92, df = 19, p = .37$	0.19
SPEM gain 24°/s	95.32	10.58	95.89	11.10	$r = 0.31, p = .17$	ICC = 0.31, $p > .10$	25.45	$t = -0.21, df = 20, p = .84$	−0.05
SPEM gain 36°/s	89.59	9.03	88.34	11.77	$r = 0.81, p < .001$	ICC = 0.77, $p < .01$	14.31	$t = 0.84, df = 19, p = .41$	0.18
SPEM gain 48°/s	71.85	16.00	70.34	14.89	$r = 0.71, p < .001$	ICC = 0.70, $p < .01$	23.71	$t = 0.58, df = 20, p = .57$	0.13
AS 12°/s	0.15	0.21	0.15	0.19	$r = 0.94, p < .001$	ICC = 0.93, $p < .01$	0.15	$t = 0.53, df = 19, p = .60$	0.02
AS 24°/s	0.40	0.30	0.44	0.41	$r = 0.59, p = .005$	ICC = 0.56, $p < .01$	0.68	$t = -0.51, df = 20, p = .62$	−0.12
AS 36°/s	0.63	0.36	0.50	0.32	$r = 0.79, p < .001$	ICC = 0.73, $p < .01$	0.45	$t = 2.25, df = 19, p = .04$	0.57
AS 48°/s	0.50	0.35	0.44	0.37	$r = 0.59, p = .004$	ICC = 0.58, $p < .01$	0.65	$t = 0.89, df = 20, p = .38$	0.18
CUS 12°/s	0.29	0.09	0.26	0.14	$r = 0.42, p = .07$	ICC = 0.34, $p > .10$	0.22	$t = 1.82, df = 19, p = .08$	0.27
CUS 24°/s	1.01	0.39	0.96	0.27	$r = 0.64, p = .002$	ICC = 0.59, $p < .01$	0.61	$t = 0.70, df = 20, p = .49$	0.17
CUS 36°/s	1.84	0.66	1.69	0.70	$r = 0.60, p = .005$	ICC = 0.58, $p < .01$	1.23	$t = 0.96, df = 19, p = .35$	0.25
CUS 48°/s	2.37	0.74	2.52	0.79	$r = 0.59, p = .005$	ICC = 0.58, $p < .01$	1.38	$t = -0.99, df = 20, p = .33$	−0.22
Fixation *N* saccades/s	0.01	0.02	0.008	0.02	$r = 0.55, p = .02$	ICC = 0.54, $p < .02$	0.04	$t = 0.57, df = 17, p = .58$	0.13
Antisaccade gain	−119.17	40.33	−98.20	28.37	$r = 0.51, p = .02$	ICC = 0.35, $p > .10$	71.37	$t = -2.69, df = 20, p = .01$	−0.59
Antisaccade spatial error	51.72	26.30	39.62	9.71	$r = 0.30, p = .18$	ICC = 0.09, $p > .10$	50.26	$t = 2.21, df = 20, p = .04$	0.48
Antisaccade latency	285.09	31.94	278.09	26.45	$r = 0.69, p = .001$	ICC = 0.65, $p < .01$	47.07	$t = 1.36, df = 20, p = .19$	0.30
Antisaccade error rate	20.90	15.14	16.40	11.02	$r = 0.89, p < .001$	ICC = 0.79, $p < .01$	14.59	$t = 2.83, df = 20, p = .01$	0.62
Prosaccade gain	102.26	8.39	98.60	8.02	$r = 0.67, p = .001$	ICC = 0.59, $p < .01$	13.27	$t = 2.53, df = 20, p = .02$	0.55
Prosaccade spatial error	15.12	4.65	14.29	4.13	$r = 0.15, p = .53$	ICC = 0.14, $p > .10$	11.50	$t = 0.66, df = 20, p = .52$	0.18
Prosaccade latency	183.01	18.80	187.90	19.13	$r = 0.79, p < .001$	ICC = 0.76, $p < .01$	24.43	$t = -1.83, df = 20, p = .08$	−0.40

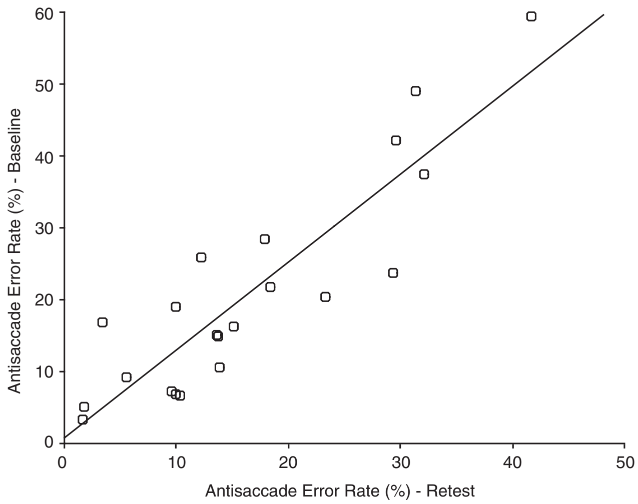

Figure 1. Relationship between antisaccade error rate at baseline and retest.

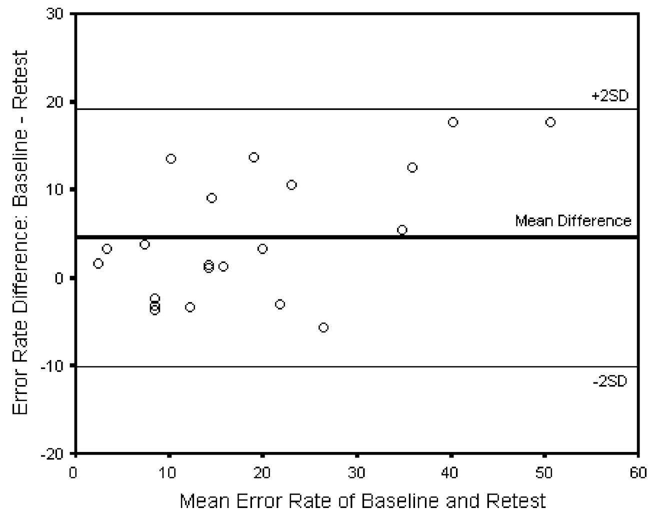

Figure 2. Relationship between difference and mean of antisaccade error rate for baseline and retest.

ICC and Pearson correlations were obtained for SPEM gain at 12°/s and 24°/s, CUS frequency at 12°/s (which reached trend level for Pearson correlation), antisaccade gain (which was significant for Pearson correlation), and prosaccade spatial error. Antisaccade spatial error became reliable after removal of an obvious outlier: $r = 0.77$; $p < .001$; ICC = 0.54; $p < .01$.

Between-Session Effects

For SPEM variables, only two comparisons yielded small changes between sessions (Table 1). At retest participants made fewer AS at 36°/s ($t = 2.25$; $df = 19$; $p = .04$) and nonsignificantly fewer CUS at 12°/s ($t = 1.82$; $df = 19$; $p = .08$). All other comparisons for SPEM and fixation variables were nonsignificant (all $p > .33$).

Concerning saccadic variables, a significant reduction in antisaccade error rate was found ($t = 2.83$; $df = 20$; $p = .01$). Saccadic performance at retest was also characterised by more accurate antisaccade gain ($t = -2.69$; $df = 20$; $p = .01$) and spatial error ($t = 2.21$; $df = 20$; $p = .04$) and reduced prosaccade gain ($t = 2.53$; $df = 20$; $p = .02$).

To investigate whether magnitude of improvement on antisaccade error rate was related to overall performance on this measure, the difference score (baseline score − retest score) was plotted against the average antisaccade error rate of baseline and retest (Bland & Altman, 1986). The relationship was statistically significant ($r = 0.58$; $p = .006$), indicating that greater improvements occurred for participants with higher average error scores (Figure 2). A similar relationship was obtained for antisaccade spatial error ($r = 0.78$; $p < .001$), indicating that greatest reductions in spatial error from baseline to retest occurred for individuals with highest average spatial error scores. No significant correlations were obtained for other variables showing significant between-session changes (all $p > .08$).

Internal Consistency

Cronbach's alpha coefficients indicated very high internal consistency (alpha ≥ 0.73) for all but three variables (AS at 48°/s; CUS at 12°/s; frequency of saccades during fixation; Table 2).

Within-Session Effects

Due to significant Mauchly's tests of sphericity, epsilon corrections of degrees of freedom were made for the following variables: SPEM gain at 36°/s (epsilon = 0.75), SPEM gain at 48°/s (epsilon = 0.74), AS at 12°/s (epsilon = 0.78), CUS at 12°/s (epsilon = 0.69), antisaccade latency (epsilon = 0.65), and prosaccade latency (epsilon = 0.61). The p and F values of within-session analyses reported in the following are virtually identical to those of analyses assuming sphericity.

Within the baseline session, there was a linear reduction of CUS frequency at 12°/s, $F(2.07,57.85) = 6.09$, $p = 0.004$, and 36°/s, $F(3,81) = 3.39$, $p = .02$. AS frequency at 36°/s increased significantly and linearly over time, $F(3, 83) = 8.48$, $p < .001$. No other significant within-session changes were observed, $p > .08$ (see Table 2).

Investigating within-session changes at retest for variables that differed between baseline and retest, it was found that there was a trend for a significant effect for antisaccade gain, $F(3,60) = 2.59$, $p = .06$. Within-subjects contrasts revealed that this was a cubic, $F(1,20) = 9.08$, $p = .007$, but not a linear, $F(1,20) = 0.20$, $p = .90$, effect, indicating that largest antisaccade gain scores were observed during the first and third segments; smaller scores were observed during the second and fourth segments. There were no within-session changes for antisaccade error rate, antisaccade spatial error, AS at 36°/s, and CUS at 12°/s, all $p > .11$.

Figure 3 depicts the between-session differences on antisaccade error rate in the absence of significant within-session changes. There were no within-session changes for both sessions combined, $F(3,60) = 1.97$, $p = .13$, and no Between × Within-Session interaction, $F(1,60) = 1.23$, $p = .31$.

Discussion

The findings from this study are as follows. First, oculomotor performance was generally stable over time. Second, effects of practice were observed most consistently on the antisaccade task, indicated by reduced error rate and improved spatial accuracy at retest. Third, the oculomotor tasks studied here generally demonstrated excellent internal reliabilities in the absence of consistent within-session changes, pointing to highly stable performance within one test session.

Table 2. *Cronbach's Alpha and Within-Session Changes on Oculomotor Variables at Baseline (N = 31)*

	Cronbach's alpha	Within-session changes
SPEM gain 12°/s	0.83	$F(3,87) = 0.20$, $p = .90$
SPEM gain 24°/s	0.85	$F(3,87) = 0.63$, $p = .60$
SPEM gain 36°/s	0.85	$F(2.23,62.54) = 0.03$, $p = .98$
SPEM gain 48°/s	0.88	$F(2.22,64.31) = 1.44$, $p = .24$
AS 12°/s	0.88	$F(2.35,65.79) = 1.76$, $p = .18$
AS 24°/s	0.80	$F(3,84) = 1.95$, $p = .13$
AS 36°/s	0.73	$F(3,83) = 8.48$, $p < .001$
AS 48°/s	0.43	$F(3,84) = 1.19$, $p = .32$
CUS 12°/s	0.34	$F(2.07,57.85) = 6.09$, $p = .004$
CUS 24°/s	0.76	$F(3,84) = 1.04$, $p = .38$
CUS 36°/s	0.85	$F(3,81) = 3.39$, $p = .02$
CUS 48°/s	0.82	$F(3,84) = 2.36$, $p = .08$
Fixation *N* saccades/s	0.45	$F(3,84) = 0.95$, $p = .42$
Antisaccade gain	0.94	$F(3,90) = 0.07$, $p = .98$
Antisaccade spatial error	0.93	$F(3,90) = 0.36$, $p = .78$
Antisaccade latency	0.85	$F(1.95,58.57) = 0.74$, $p = .48$
Antisaccade error rate	0.87	$F(3,90) = 0.45$, $p = .89$
Prosaccade gain	0.91	$F(3,90) = 1.55$, $p = .21$
Prosaccade spatial error	0.93	$F(3,90) = 4.32$, $p = .07$
Prosaccade latency	0.89	$F(1.83,54.80) = 0.43$, $p = .64$

Test-Retest Reliability

Previous studies have pointed to good temporal stability of global quantitative and qualitative, as well as specific, measures of smooth pursuit (Campion et al., 1992; Gooding et al., 1994; Holzman et al., 1973; Iacono & Lykken, 1981; Roy-Byrne et al., 1995; Schlenker & Cohen, 1995; Yee et al., 1998). This study replicates these findings. Good Pearson correlations and ICC were obtained for most measures of pursuit gain and frequency of catch-up and anticipatory saccades during pursuit. As Becser, Sand, and Zwart (1998) pointed out, ICC > 0.75 indicate excellent reliability and ICC > 0.40 indicate good reliability. The high reliability of anticipatory saccade frequency is noteworthy given the proposed role of this measure as a schizophrenia endophenotype (Ross et al., 1998; Ross, Olincy, Harris, Radant, Hawkins, et al., 1999).

The significant test–retest reliability of the antisaccade error rate is likewise important given the hypothesis that this measure may serve as an oculomotor endophenotype (Calkins & Iacono, 2000; Clementz, 1998; Myles-Worsley et al., 1999). This is the best reliability reported to date for the error rate, and contrasts with a recent study by Klein and Berg (2001), who reported a nonsignificant correlation. One possible reason for Klein and Berg's failure to obtain significant reliability might lie in the type of antisaccade task they used, namely, the overlap version. In the overlap antisaccade task, the central target remains "on" when the peripheral target appears. This version of the antisaccade task is associated with lower error rates (Fischer & Weber, 1997), thereby arguably reducing between-subjects variability (Klein & Berg, 2001). A possible implication of this finding is that the nonoverlap task might represent a psychometrically improved measure of saccadic inhibition in healthy individuals.

The use of Pearson correlation and ICC coefficients allowed the comparison between these two measures of association and agreement, respectively (Bartko, 1991). As expected, ICC coefficients tended to be lower than Pearson correlation coefficients, thereby providing a more conservative estimate of temporal stability.

It is instructive to compare the obtained temporal stabilities of oculomotor performance with those of other psychophysiological, neuropsychological, and schizotypal personality trait measures used in schizophrenia research. Mathalon, Ford, and Pfefferbaum (2000) observed ICC for the electrophysiological measure of P300 amplitude of between 0.84 and 0.93. Cadenhead, Carasso, Swerdlow, Geyer, and Braff (1999) reported somewhat higher ICC for a measure of sensorimotor gating, namely, prepulse inhibition. Most of the coefficients reported by Cadenhead et al. (1999) were above 0.80 and many were above 0.90, although very low coefficients (0.12–0.31) were also observed. Reliability coefficients of neuropsychological and schizotypal personality tests tend to be comparable to those obtained here (Vollema & van den Bosch, 1995; Wechsler, 1981, 1987).

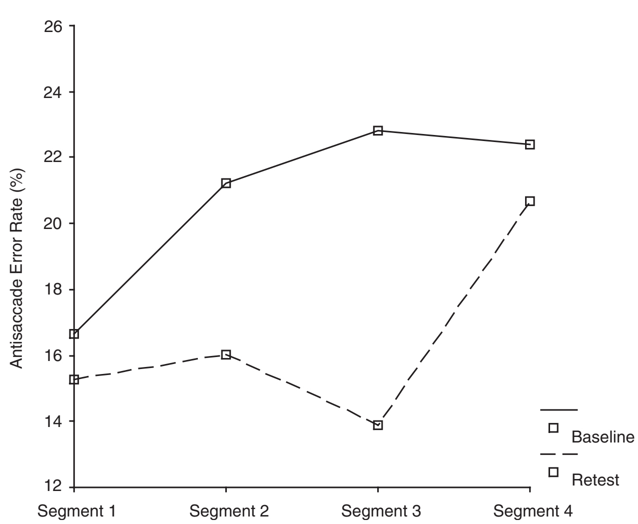

Figure 3. Within- and between-session changes on antisaccade error rate.

Internal Consistency

To our knowledge, this is the most comprehensive investigation of the internal consistency of specific oculomotor measures used in schizophrenia spectrum research. Most of the key measures demonstrated very good internal consistency. Coefficients reported here are largely comparable to those reported by Cegalis and Sweeney (1979) and those of neuropsychological (Wechsler, 1981, 1987), clinical (Moniz-Cook, Woods, Gardiner, Silver, & Agar, 2001), and schizotypal personality (Vollema & van den Bosch, 1995) measures. Lund, Sponheim, Iacono, and Clementz (1995) reported Cronbach's alpha coefficients for EEG power spectra. These were found to be somewhat higher than the current reliabilities, with most coefficients above 0.9.

Internal consistency is an important issue for psychophysiological research. Most assessments of brain function using psychophysiological tasks rely on obtaining multiple performance samples (e.g., trials) and subsequently averaging these. Calculating averages is necessitated by statistical analyses. However, the validity of this approach assumes that measures of brain function are consistent over an extended period of time (or several trials). With a few exceptions (Lund et al., 1995), this consistency has often not been demonstrated. The present study demonstrates consistent oculomotor control and a relative absence of significant within-session practice effects in healthy individuals (with the exception of some improvement on the SPEM task), thereby validating the subsequent averaging of performance data for each participant. The extent to which these reliability findings generalize to schizophrenia patients remains to be investigated.

Within- and Between-Session Effects

Some within-session performance changes at baseline were demonstrated. Reductions in catch-up saccade frequency during pursuit were observed, consistent with the notion that the eye requires some time to optimally follow a moving target (Leigh & Zee, 1999). However, an *increase* in anticipatory saccade frequency over time was also observed at one velocity; the reason for this finding is unclear. The reason why no within-session improvements were observed on saccadic reaction times might be related to the random spatial and temporal characteristics of peripheral targets used in the present study. This randomization may have limited capacities for procedural learning, commonly observed during performance of fixed motor response sequences (Corr, Pickering, & Gray, 1997; Kumari et al., 1997).

The most systematic changes *between* sessions were observed on the antisaccade task. Antisaccade error rate significantly and considerably reduced from baseline to retest (with the largest effect size in this study). Additionally, there was evidence of improved accuracy (using measures of both antisaccade gain and spatial error) and slightly faster latency. This pattern of practice effects is compatible with previous research (Green et al., 2000; Klein et al., 2002). The reduction in error rate from first to second assessment observed in healthy individuals by Green et al. (from 21.1% to 14.5%) was very similar to that observed here (from 20.9% to 16.4%), despite different time intervals between baseline and retest in Green et al.'s study (1 week) and ours (2 months).

No within-session practice effects were observed for the antisaccade error rate at either assessment; indeed, Figure 3 suggests small *increases* in error rate during each session, possibly due to fatigue or reduced motivation. It may thus be argued that between-session improvements on this measure are not due to fast learning gains, but due to slow and time-dependent learning processes (Hauptmann & Karni, 2002). These learning processes may include effects of memory and motor consolidation (Shadmehr & Holcomb, 1997) as well as increased familiarity with the laboratory environment and consequently reduced anxiety levels (DeRosa & Patalano, 1991; Lister & Hilakivi, 1988).

The magnitude of the improvement on the antisaccade error rate as well as spatial error from the first to the second assessment was related to overall performance (Fig. 2). Previous research into the cholinergic mechanisms of learning has similarly demonstrated that the strongest learning benefits occur for participants with the worst performance (Sitaram, Weingartner, & Gillin, 1978), possibly due to the existence of ceiling (or, in the case of the error rate, bottom) effects in well-performing participants.

Lezak (1983) suggested that practice effects in cognitive assessments are observed particularly on tests that "require an unfamiliar or infrequently practiced mode of response" (p. 115). The antisaccade task can be described as both unfamiliar and infrequently practiced, and is thereby susceptible to practice effects. As Ahonniska, Ahonen, Aro, Tolvanen, and Lyytinen (2001) pointed out, between-session practice effects are not commonly observed on tests related to steadiness of motor control or reaction times, perhaps explaining the absence of consistent practice effects on the SPEM task and prosaccade latency in the present study.

Practice effects on the antisaccade task have to be taken into consideration in studies using parallel (between-group) designs involving repeated assessments (within-subjects), such as clinical studies of treatment effects. Rate and magnitude of learning across sessions may vary between groups and, therefore, confound interaction effects of group and treatment.

Conclusions

To conclude, oculomotor measures used as endophenotypes in schizophrenia research were assessed in this study on a number of reliability criteria. Test–retest reliabilities and internal consistencies were found to be good for most measures, supporting the trait nature of oculomotor measures and the reliability of their assessment. Our findings point to the existence of between- but not within-session practice effects on the antisaccade task, which have to be considered in longitudinal studies.

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