Smooth pursuit eye tracking and visual fixation in psychosis-prone individuals

By: Diane C Gooding, Meghan D Miller and Thomas R Kwapil

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Abstract:

Subjects identified by Perceptual Aberration-Magical Ideation (Per-Mag) scores (n=97), Social Anhedonia (SocAnh) scores (n=45), and Physical Anhedonia (PhysAnh) scores (n=31) as well as normal controls (n=94), underwent psychophysiological and clinical assessment. This is the first published investigation of pursuit system functioning in three groups of questionnaire-identified at-risk individuals. Pursuit during a simple non-monitor tracking task was measured using root-mean-square error (RMSE) scores and pursuit gain scores. Fixation performance was measured in terms of number of saccades away from the central fixation point. The at-risk subjects were more likely to display aberrant smooth pursuit tracking than controls, though there were no significant differences between the at-risk subjects endorsing items relevant to positive-symptom schizotypy and those endorsing items pertaining to negative-symptom schizotypy. The groups did not differ significantly in their visual fixation performance. Participants were also evaluated for the presence of Axis I symptomatology and psychotic-like experiences. Neither the experimental subjects nor the control subjects displayed a significant association between ocular motor performance and psychotic-like experiences. These findings are consistent with prior evidence that pursuit tracking is a trait characteristic, independent of clinical status.

Keywords: smooth pursuit eye tracking | visual fixation | schizotypy | social anhedonia | perceptual aberration | physical anhedonia | psychotic-like experiences | psychology

Article:

1. Introduction

During smooth pursuit eye tracking, the eyes visually follow a slowly moving target by matching the velocity of the target and inhibiting saccades (Leigh and Zee, 1991). During visual fixation, gaze is maintained upon a stationary target. Controversy exists regarding the relationship between smooth pursuit eye tracking and visual fixation; while some investigators posit a shared system underlying both pursuit and fixation (cf. Krauzlis and Miles, 1996), others maintain that fixation is not simply pursuit of a target moving at zero velocity (Luebke and Robinson, 1988). Abnormal fixation, like abnormal smooth pursuit, is often characterized by an increased frequency and/or amplitude of intrusive saccadic movements resulting in gaze deviation. Both smooth pursuit eye tracking and visual fixation abnormalities have been proposed as potential markers of a schizophrenia diathesis.

1.1. Identification of individuals at risk for schizophrenia

The identification of individuals at risk for schizophrenia should greatly enhance our understanding of the etiology of the disorder and may hasten the development of prophylactic treatment interventions. Such at-risk individuals are often referred to as schizotypic ([Meehl, 1962] and [Meehl, 1990]) or psychosis-prone (Chapman and Chapman, 1985). It is hypothesized that the majority of these individuals will never develop full-blown schizophrenia, though they may experience subtle clinical and psychophysiological manifestations of this vulnerability.

Individuals may be classified as being at heightened risk for schizophrenia on the basis of any of the following indicators: their biological relationship to a person with schizophrenia (cf. Erlenmeyer-Kimling et al., 1995); deviance on an empirically validated biobehavioral marker of risk for schizophrenia (Gooding and Iacono, 1995); deviance on an empirically established indicator of schizotypy, such as the Chapman psychosis-proneness scales (Chapman et al., 1994); or meeting Axis II diagnostic criteria for a Cluster A personality disorder such as schizotypal personality disorder (Erlenmeyer-Kimling et al., 1995).

1.2. Psychometric identification of risk

Using the psychometric high-risk strategy, investigations have focussed on individuals defined as at-risk on the basis of scores the Chapman psychosis-proneness scales. Inspired in part by the description of schizotypy by Meehl (1964), the Chapmans developed a series of scales designed to identify individuals with body-image distortion, perceptual aberrations, magical ideation, and/or anhedonia (cf. Chapman et al., 1995). Longitudinal investigation has shown that the Perceptual Aberration Scale (Chapman et al., 1978) identifies a subgroup of psychosis-prone individuals, some of whom eventually manifest a psychotic disorder (Chapman et al., 1994). However, the follow-up of these individuals has revealed a heterogeneous outcome, with a heightened prevalence of both mood psychoses and schizophrenia.

Kwapil (1998) reported that although high scorers on the Social Anhedonia Scale do not differ markedly from control subjects on cross-sectional measures of psychosis-proneness, longitudinal data suggest that these subjects are especially psychosis-prone at 10-year follow-up. More recently, Kwapil (1998) reported that 24% of high scorers on the revised Social Anhedonia Scale (Eckblad et al., 1982) were diagnosed with schizophrenia-spectrum disorders at the follow-up, compared to only 1% of the control group. These findings suggest that the Social Anhedonia Scale, unlike the Perceptual Aberration Scale, may identify individuals at specific risk for the development of schizophrenia-spectrum disorders.

To date, the Physical Anhedonia Scale has not proved useful in predicting either psychosis or psychosis-proneness in the general population (Chapman et al., 1994). However, in cross-sectional research, high scorers on the Physical Anhedonia Scale display psychophysiological patterns that are similar to those observed in schizophrenia patients (Miller and Yee, 1994). Additionally, the Physical Anhedonia Scale appears useful in samples of first-degree relatives of schizophrenia probands. The Physical Anhedonia Scale successfully distinguishes first-degree relatives of schizophrenia patients from normal controls ([Katsanis et al., 1990] and [Franke et al., 1994]). Moreover, in the New York High Risk Project ([Erlenmeyer-Kimling et al., 1995] and [Freedman et al., 1998]), individuals identified by the Physical Anhedonia Scale showed increased rates of psychosis in females and poorer social adjustment in adulthood.

1.3. Smooth pursuit eye tracking and risk for schizophrenia

Impaired smooth pursuit eye tracking is now recognized as a biobehavioral marker of risk for schizophrenia (cf. Iacono, 1993). The vast literature regarding the prevalence of smooth pursuit eye tracking abnormalities in first-degree relatives of individuals with schizophrenia will not be reviewed here; interested readers are referred to Iacono (1993).

Siever and associates have demonstrated the feasibility of identifying at-risk individuals on the basis of variables observed to differentiate schizophrenia patients from controls (Siever and Coursey, 1985). [Siever et al., 1982] and [Siever et al., 1984] found that college students with low-accuracy pursuit tracking were more likely to display schizotypal characteristics, such as social introversion, anhedonia, and difficulty in interpersonal relations, than college students with high-accuracy tracking. In a later study, [Siever et al., 1990] and [Siever et al., 1994] observed that individuals with schizotypal personality disorder (n=26) not only displayed significantly worse tracking than normal controls, but also showed an association between their eye tracking performance and deficit-like symptoms of schizotypal personality disorder.

There have been a few studies of smooth pursuit tracking performance in questionnaire-identified at-risk persons. Simons and Katkin (1985) demonstrated the feasibility of identifying individuals with high scores on the Chapman Psychosis-proneness Scales who also display deviant smooth pursuit. In their seminal series of studies, they revealed that schizotypic individuals selected on the basis of either the Physical Anhedonia Scale or the Perceptual Aberration Scale produced more variable and, in some cases, more deviant eye tracking records than control subjects.

Lencz et al. (1993) studied the eye tracking records of 55 college undergraduates prescreened with another self-report measure of schizotypy, namely, the Schizotypal Personality Questionnaire (SPQ; Raine, 1991). Their resultant sample of non-patient students who met diagnostic criteria for schizotypal personality disorder showed, as measured by qualitative ratings, than the normal comparison group. Similarly, O'Driscoll et al. (1998) observed that the eye tracking records of subjects (n=31) with elevated self-reported experiences of perceptual anomalies had significantly lower pursuit quality than those of normal control subjects (n=24). Limitations of previous investigations of smooth pursuit tracking in questionnaire-identified at-risk individuals include relatively small samples, as well as reliance upon qualitative ratings, which have limited heuristic value in elucidating the neural basis of the eye tracking abnormalities. To date, there have been no studies of pursuit tracking performance in individuals identified on the basis of their Social Anhedonia Scale scores.

1.4. Visual fixation and risk for schizophrenia

There has been renewed interest in visual fixation abnormality as a potential marker of risk for schizophrenia (cf. Amador et al., 1995). Although several studies ([Mialet and Pichot, 1981], [Gaebel et al., 1986], [Matsue et al., 1986] and [Amador et al., 1991]) indicate that visual fixation abnormalities are more prevalent among schizophrenia patients than normal controls, a recent investigation by Kissler and Clementz (1998), using quantitative analyses, yielded negative findings. There is also suggestive evidence that the first-degree relatives of schizophrenia patients are more likely to exhibit fixation deficits than the general population (cf. Amador et al., 1995). To date, there are no published studies concerning visual fixation performance in questionnaire-identified at-risk individuals.

1.5. The present investigation of pursuit tracking and fixation

The purpose of the present investigation is to examine the relationship between pursuit performance and psychometric performance on the Chapman psychosis-proneness Scales. We examined two forms of pursuit behavior, namely, smooth pursuit eye tracking and visual fixation. Given that psychosis-proneness has two main factors, namely, cognitive/perceptual distortion and anhedonia ([Kelley and Coursey, 1992] and [Lipp et al., 1994]), we were interested in examining the performance of individuals with deviant scores on the Physical Anhedonia Scale and the Social Anhedonia Scale as well as examining the performance of high scorers on the Perceptual Aberration and/or Magical Ideation Scales. Our interest in a group of individuals with deviant scores on the Social Anhedonia Scale also reflects renewed interest in the Scale following the report by Kwapil (1998) indicating that the Social Anhedonia Scale may identify individuals at specific risk for the development of schizophrenia-spectrum disorders.

The present investigation extends the research literature by: (a) examining a larger sample of at-risk subjects, including those identified on the basis of their scores on the revised Social Anhedonia Scale; (b) studying the pursuit performance using a quantitative measure of smooth pursuit tracking performance, namely, root-mean-square error (Clementz et al., 1996); (c) investigating the fixation performance of the same individuals; and (d) examining the relationship between pursuit tracking and fixation performance. We hypothesized that all psychosis-prone subjects would display pursuit tracking and visual fixation abnormalities compared to control subjects. We expected that the psychosis-prone individuals would produce a significantly higher number of saccades during pursuit tracking and visual fixation. On the basis of prior studies indicating an association between eye tracking deficits and negative symptoms in schizophrenia (cf. [Katsanis and Iacono, 1991] and [Roitman et al., 1997]), we predicted that individuals reporting elevated levels of anhedonia would produce poorer eye tracking than the individuals reporting cognitive/perceptual distortions. Finally, we expected that the individuals who produced smooth pursuit eye tracking impairments would also show poorer performance on the fixation task.

2. Method

2.1. Psychometric screening

The high-risk and control subjects were drawn from a sample of 1700 male and 2300 female undergraduate students enrolled in introductory psychology courses at a mid-western university. The psychosis-prone individuals were identified by their aberrant responses to Chapman

Psychosis-proneness Scales. Psychometric screening was performed using a 179-item true–false self-report questionnaire composed of the four Chapman psychosis-proneness Scales, namely, the Perceptual Aberration, Magical Ideation, revised Social Anhedonia, and revised Physical Anhedonia Scales ([Chapman et al., 1976], [Chapman et al., 1978], [Eckblad et al., 1982] and [Eckblad and Chapman, 1983]). In order to minimize test-taking biases, we included the Chapman Infrequency Scale (Chapman and Chapman, 1983), a Scale composed of infrequent items, and excluded any participants who endorsed three or more items.

2.2. Sample

There were four undergraduate groups, including three psychosis-prone groups (Per-Mag, Social Anhedonia, and Physical Anhedonia) and one control group. Participants who scored at least 2 S.D. beyond the same-sex sample mean on either the Magical Ideation or the Perceptual Aberration Scale were included in the Per-Mag group. Typically, the Magical Ideation and Perceptual Aberration Scales are highly and positively correlated ([Chapman and Chapman, 1985] and [Chapman et al., 1982]); in our sample the intercorrelation of these Scales was also high ($r=0.75$). The Social Anhedonia (SocAnh) group included individuals who scored at least 2 S.D. beyond the same-sex mean scores on the revised Social Anhedonia Scale. The Social Anhedonia Scale was not significantly correlated with either the Perceptual Aberration Scale or the Magical Ideation Scale, $r=0.10$ and 0.04 (n.s.), respectively. The two anhedonia Scales were moderately correlated ($r=0.46$); assignments for the anhedonia groups were made according to the highest Scale score. Thus, the Physical Anhedonia (PhysAnh) group included individuals who scored at least 2 S.D. beyond the same-sex mean scores on the revised Physical Anhedonia Scale and whose highest score elevation was on the Physical Anhedonia Scale.

The control group comprised a randomly selected set of individuals whose scores on all four Chapman Scales were below 0.5 S.D. of the same-sex sample mean. Control subjects were also screened for personal and family history of psychosis. Any subjects who had a history of strabismus, epilepsy, multiple sclerosis, or any other condition which might adversely affect ocular motor functioning were excluded from subsequent analyses. The resultant sample consisted of 268 undergraduates: 97 Per-Mag subjects (42 male, 55 female); 45 SocAnh subjects (15 male, 30 female); 31 PhysAnh subjects (15 male, 16 female); and 94 control subjects (46 male, 48 female).

2.3. Psychophysiological assessment

A 33-cm monitor located 53 cm from the subject's nasion was used to present the stimuli. The target was a luminous red circle (approx. 1 cm in diameter) which was presented against a darkened computer screen. All subjects were tested in a dimly illuminated room with the Eyelink System (Reingold and Stampe, 1996), a system with a temporal resolution of 4 ms and a spatial resolution of 0.25° of visual angle, eye position was recorded by an infrared reflection technique. Subjects' head movements were recorded by the headband's head camera which picked up phototransistor signals from four diode strips mounted to the computer monitor. The target subtended an arc of ±10° from center fixation.

In the smooth pursuit tracking task, subjects visually followed the target stimulus which moved in horizontal sinusoidal motion at 0.4 Hz. There were three 50-s trials of this task; subjects' performances across all three trials were scored and averaged in order to obtain the most reliable estimate. Pursuit tracking performance was assessed using the root-mean-square error (RMSE) measure, pursuit gain, total number of saccades emitted, and total number of anticipatory saccades. The RMSE measure was chosen for inclusion because of its well-documented psychometric properties (see [Iacono and Lykken, 1979a], [Iacono and Lykken, 1979b] and [Gooding et al., 1994]). Root-mean-square error is operationally defined as the error deviation between digitized representations of the target channel and the subject's eye movement response channel. In order to reduce the skewedness of the data, RMSE scores were transformed using log10 (Winer et al., 1991). Lower RMSE scores are associated with better tracking performance.

Pursuit gain was chosen as a measure of tracking performance because it is a biologically meaningful measure; eye velocity has been related to activity in the frontal eye fields (cf. Sweeney et al., 1998). Gain is operationally defined as the peak eye velocity divided by the peak target velocity (Iacono, 1993). Gain, the mean across a window of time when the target was moving the fastest, was assessed for all three trials of pursuit and averaged. Higher gain scores are associated with better pursuit performance.

Saccades were tallied using a computer algorithm designed to detect non-blink events where eye acceleration exceeded 600°/s and were verified by visual inspection. Saccades greater than 0.25° of visual angle were identified. Two saccadic measures were used, namely, the total number of saccades greater than 0.25° and the total number of anticipatory saccades. An anticipatory saccade was operationally defined as a saccadic event of at least 4° in amplitude which, although in the direction of target motion, served to increase positional error; this operational definition has been used by others (cf. Whicker et al., 1985). At times anticipatory saccades were generated in a series of multiple events; when this occurred, their composite amplitude was required to be at least 4°. For all anticipatory saccades, during the initial saccadic event, there was no pursuit, and following the saccadic event(s), there were at least 150 ms of slowed pursuit.

In the visual fixation task, subjects were instructed to maintain their gaze on a central fixation point without blinking or looking away from the target. There were three 30-s trials of this task. Fixation performance was assessed by tallying the total number of saccades (>1°) that were generated during each trial; these scores were averaged across the three trials. All eye movement data analyses were conducted after off-line filtering. Scoring of eye tracking records was performed by investigators naive to group membership. Software for stimulus presentation and data acquisition was developed by Dr Eyal Reingold and Dr David Stampe.

2.4. Neurocognitive assessment

IQ was measured in order to provide further description of the undergraduate sample. Time constraints precluded the use of the entire revised Wechsler Adult Intelligence Scale (WAIS-R; Wechsler, 1981). Vocabulary and Block Design subtests were administered in order to obtain an estimate of participants' full Scale IQ scores. This two-subtest short form of the WAIS-R (Silverstein, 1982) yields scores that are highly correlated with full Scale scores, though they overestimate full Scale iq by an average of two points (Ryan et al., 1988).

2.5. Clinical assessment

All subjects were interviewed by independent investigators naive to subjects' group membership and ocular motor performance. Subjects were interviewed using the Mood Disorder and Psychoactive Substance Use Disorder sections from the SCID-IV (Spitzer et al., 1993) as well as the Wisconsin Manual of Psychotic-Like Experiences ([Chapman and Chapman, 1980] and [Kwapil et al., 1999]). Prior research (Allen et al., 1987) indicates that psychosis-prone individuals may demonstrate mild and/or transient forms of the experiences and symptoms reported by schizophrenic patients; these experiences are termed 'psychotic-like experiences.' Subjects were rated for the presence, frequency, and severity of the following psychotic-like experiences: transmission of thoughts, passivity experiences, auditory experiences, thought withdrawal, aberrant beliefs, visual experiences, and olfactory experiences. Each experience is rated on an 11-point Scale of deviancy, where scores of 2–5 reflect psychotic-like experiences and scores of 6–11 are assigned for psychotic experiences. Analyses from the Chapman longitudinal follow-up (Chapman et al., 1994) indicated that a cutoff of 4 or above for the highest single rating was an effective predictor of later psychosis.

2.6. Procedures

Following the screening procedure using the Chapman psychosis-proneness scales, potential study participants were contacted by telephone and invited to participate in a study of ‘individual differences in brain functioning’. The study was a multiple-session investigation involving neuropsychological, psychophysiological, and clinical assessment. For the remainder of the study participation, all students were tested individually. Participants either received course credit or monetary remuneration for their participation. All study staff members were naive to a potential participant’s group membership throughout recruitment, testing, and scoring. Sample selection and recruitment occurred over four consecutive semesters. All participants gave their informed consent.

3. Results

3.1. Demographic characteristics

Table 1 provides the mean age and estimated full-Scale IQ scores for the subject groups. The subject groups did not differ in age or mean estimated IQ, $F_{3,263}=0.31$ and 0.44 (n.s.), respectively. This was a young (mean age 18.73 years), bright (mean estimated full-Scale IQ, 117) sample. Although the groups were not formally matched, χ^2 analyses revealed no significant between-group differences in terms of gender, $\chi^2(3)=3.26$ (n.s.).

Table 1. Demographic and clinical characteristics

	Group			
	Per-Mag (*n*=97) Mean (S.D.)	SocAnh (*n*=45) Mean (S.D.)	PhysAnh (*n*=31) Mean (S.D.)	Control (*n*=94) Mean (S.D.)
Chapman Scale[a]				
PA	20.35 (6.1)	9.64 (5.3)	6.97 (6.2)	4.13 (3.1)
MI	20.73 (5.5)	10.16 (5.0)	7.03 (6.8)	5.68 (4.0)

	Group			
	Per-Mag (*n*=97) Mean (S.D.)	SocAnh (*n*=45) Mean (S.D.)	PhysAnh (*n*=31) Mean (S.D.)	Control (*n*=94) Mean (S.D.)
rSA	8.25 (4.5)	21.47 (4.6)	13.34 (7.3)	4.53 (2.9)
rPA	7.59 (4.0)	13.36 (5.0)	26.03 (4.5)	8.40 (4.2)
Age	18.76 (0.80)	18.78 (0.88)	18.61 (0.75)	18.72 (0.86)
FSIQ[b]	116.91 (12.05)	119.16 (11.36)	116.45 (12.49)	117.54 (11.99)
Psychotic-like				
experiences[c]	2.18 (2.2)	1.36 (1.5)	0.81 (1.0)	0.63 (0.7)

a Means and standard deviations for each of the Chapman psychosis-proneness Scales: Perceptual Aberration (PA); Magical Ideation (MI); revised Social Anhedonia (rSA); and revised Physical Anhedonia (rPA).

b Full Scale IQ scores estimated from WAIS-R Vocabulary and Block Design subtests.

c Highest (most deviant) single rating of psychotic-like experiences for each subject.

3.2. Smooth pursuit tracking performance

Mean scores for the subject groups are provided in Table 2. The RMSE scores were log10-transformed in order to reduce their skewedness. Overall, there was a significant group difference in pursuit performance, as measured by either RMSE or gain, $F_{3,263}=3.59$ and 3.45, $P<0.05$, respectively. As expected, the RMSE and gain scores were negatively associated with each other, $r=-0.81$, $P<0.001$.

Table 2. Oculomotor performance

	Group			
	Per-Mag (*n*=97) Mean (S.D.)	SocAnh (*n*=45) Mean (S.D.)	PhysAnh (*n*=31) Mean (S.D.)	Control (*n*=94) Mean (S.D.)
Smooth pursuit eye tracking				
Log RMSE[a]	1.86±0.23	1.79±0.23	1.91±0.26	1.79±0.21
Gain[b]	0.85±0.09	0.86±0.08	0.83±0.11	0.88±0.08
Total saccades[c]	103.96±25.4	99.31±28.1	104.34±21.0	99.46±23.2
Anticipatory saccades[d]	1.19±2.6	0.89±1.7	2.29±4.9	0.96±3.1
Visual fixation				
Number of saccades[e]	0.98±1.6	0.81±1.5	0.89±1.2	0.86±1.4

a Mean $\log_{10}$ root-mean-square error (RMSE) scores for each subject group; RMSE is operationally defined as the error deviation between digitized representations of the target and eye response channels. Higher scores indicate poorer pursuit performance.

b Mean pursuit gain scores for each of the subject groups; gain is operationally defined as the ratio of the peak eye velocity divided by the peak target velocity. Lower scores indicate poorer pursuit performance.

c Mean number of saccades emitted across three trials of 0.4 Hz pursuit.

d Mean number of anticipatory saccades emitted across three trials of 0.4 Hz pursuit.

e Mean number of saccades (greater than 1°) emitted during three trials of fixation.

Our a priori hypotheses were that the experimental (at-risk) groups would display poorer pursuit tracking performance than the controls. Using linear orthogonal contrasts, we performed between-group comparisons. The three at-risk groups performed significantly more poorly than the controls, whether pursuit tracking was measured by RMSE or gain, $t(263)=2.22$ and 2.76, $P<0.05$, respectively. Contrary to our expectations, the subjects who endorsed items suggestive of positive-symptom schizotypy (the Per-Mag group) did not differ significantly from the subjects who endorsed items suggestive of negative-symptom schizotypy (the SocAnh and PhysAnh groups) in terms of RMSE scores, $t(263)=0.26$, or gain scores, $t(263)=0.35$ (n.s.), respectively. Post hoc analyses revealed that the PhysAnh group had significantly poorer tracking performance, as assessed by RMSE scores, relative to the SocAnh group, $t(74)=2.18$, $P<0.05$. The difference between the two groups of anhedonia subjects was not significant when tracking was assessed using the gain measure, $t(74)=1.68$, $P=0.10$.

Given prior indications (cf. [Gooding et al., 1990] and [Gooding et al., 1997]) that root-mean-square error scores demonstrate greater sensitivity in terms of differentiating between schizophrenia patients and controls, RMSE scores were chosen for determining the presence of eye tracking dysfunction. A plotted depiction of subjects' RMSE scores is provided in Fig. 1. Deviant pursuit tracking was operationally defined as log RMSE scores beyond 2 S.D. of the control group's mean RMSE score. Very few subjects (30 of 267) displayed deviant pursuit tracking. All three at-risk groups had significantly higher proportions of deviant trackers relative to controls, $\chi 2(3)=9.72$, $P<0.05$. Sixteen percent of the Per-Mag group, 16% of the SocAnh group, 13% of the PhysAnh group, and 3% of the control subjects produced deviant RMSE scores. Both the Per-Mag and SocAnh groups exceeded the control group on the proportion of subjects with deviant RMSE scores, Fisher's Exact test, $P=0.003$ and $P=0.013$, respectively. The Physical Anhedonia group demonstrated a trend towards a greater rate than the control group, Fisher's Exact test, $P=0.069$. The three groups of at-risk subjects did not differ significantly in their proportion of deviant trackers, $\chi 2(2)=0.24$ (n.s.).

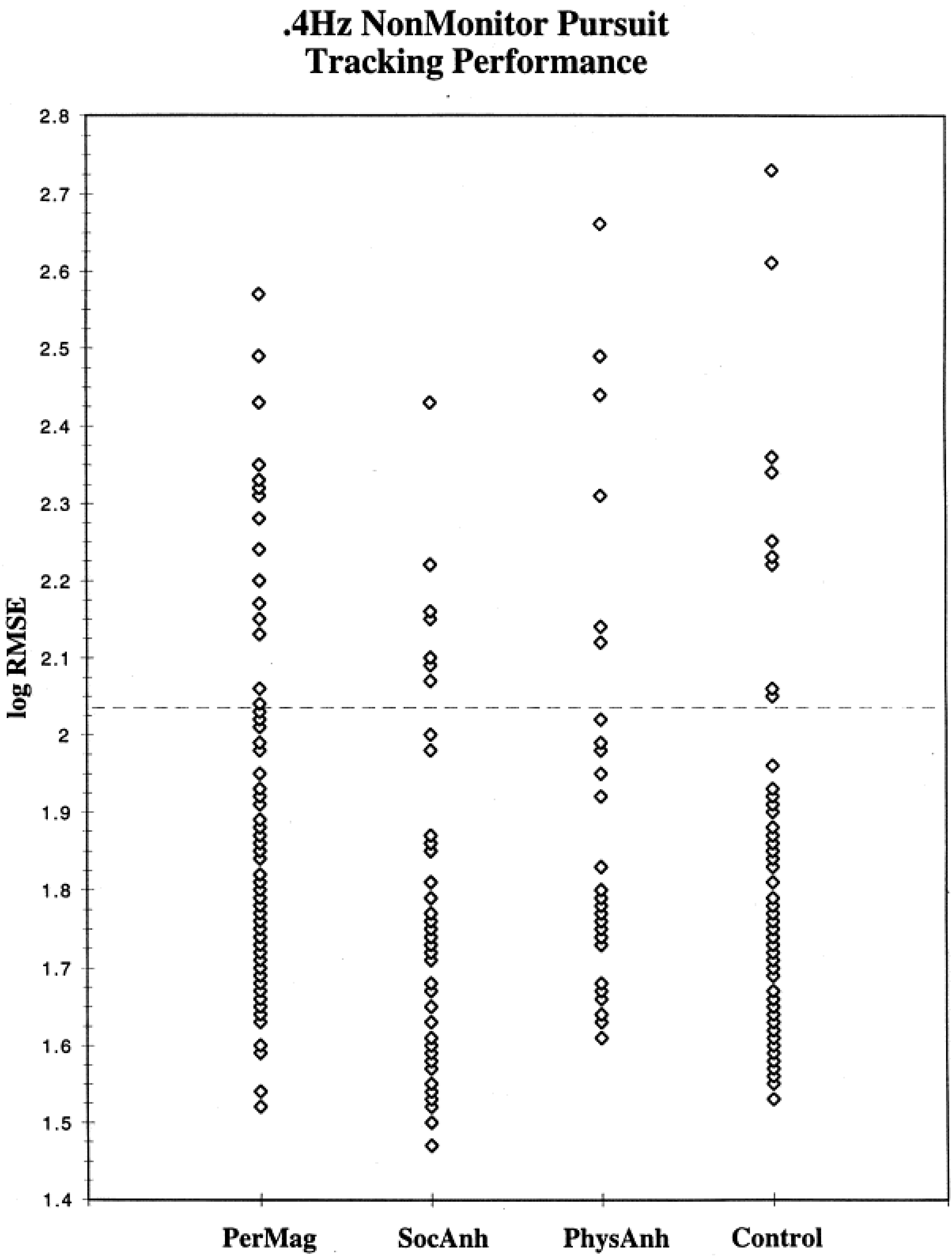

Fig. 1. Each symbol depicted may represent more than one subject with that particular root mean square error (RMSE) score. RMSE scores are log-transformed.

The number of total saccades produced during pursuit was significantly associated with the number of anticipatory saccades produced ($r=0.22$, $P<0.001$). As expected, the total number of saccades was positively associated with RMSE scores ($r=0.29$, $P<0.001$) and negatively associated with gain scores ($r=-0.41$, $P<0.001$). The total number of anticipatory saccades was more strongly correlated with both the RMSE and gain measures, $r=0.76$ and -0.75, $P<0.001$, respectively. However, the four groups did not differ significantly in mean number of total saccades produced during pursuit tracking, $F_{3,263}=0.79$ (n.s.), nor did they differ in mean number of anticipatory saccades produced across pursuit trials, $F_{3,263}=1.66$ (n.s.).

3.3. Visual fixation performance

None of the psychosis-prone groups could be distinguished from the control group by the mean number of saccades made away from the fixation point, $F_{3,263}=0.18$ (n.s.). Moreover, the four subject groups did not differ significantly in terms of their variability in fixation performance.

3.4. Relationships between smooth pursuit tracking and visual fixation

Both smooth pursuit eye tracking and visual fixation are measures of the pursuit subsystem (Leigh and Zee, 1991), and saccades disrupt the overall quality of both measures. We were interested in the relationship between saccades emitted during pursuit tracking and saccades emitted during fixation. We observed a small, non-significant association between total number of saccades emitted during pursuit tracking and number of saccades emitted during fixation, $r=0.03$ (n.s.). In contrast, we found a significant relationship between the number of anticipatory saccades emitted during tracking and the number of saccades emitted during visual fixation, $r=0.20$, $P<0.001$.

3.5. Clinical functioning

Nearly 14% (36 of 267) of the subjects had experienced at least one episode of mood disturbance. Three of the subjects had a diagnosis of bipolar illness, though all were euthymic at the time of study participation; all three had been classified in the Per-Mag group. Five of the subjects met diagnostic criteria for a current depressive episode; two had been classified in the Per-Mag group, and three had been classified in the SocAnh group. There was no association between a past history of mood disorder and deviant pursuit tracking, Fisher's exact test, $P=0.20$ (one-tailed).

None of the individuals in our sample met diagnostic criteria for a psychotic disorder. However, some of the subjects reported experiencing attenuated psychotic-like symptoms. Table 1 lists the mean rating of psychotic-like experiences for each group. There were significant group differences for their highest, most deviant single rating of psychotic-like experiences, $F_{3,263}=16.93$, $P<0.001$. As expected, the psychosis-prone subjects endorsed a greater number of psychotic-like experiences than the controls, $t(263)=5.72$, $P<0.001$. Similarly, the Per-Mag group had significantly more deviant ratings on the psychotic-like experiences interview than the SocAnh subjects, $t(119)=2.58$, $P<0.05$. Neither the at-risk or control subjects showed a significant association between their pursuit performance and psychotic-like experiences; r values ranged from −0.05 to 0.21 (n.s.).

4. Discussion

This investigation was undertaken to evaluate the feasibility of using impaired smooth pursuit eye tracking and visual fixation abnormalities as a second screening device for individuals at putative risk for schizophrenia. The individuals in this study were not biologically related to a schizophrenic proband; rather, their at-risk status stemmed from their aberrant scores on the Chapman psychosis-proneness Scales. Prior studies ([Lencz et al., 1993] and [O'Driscoll et al., 1998]) have indicated that individuals scoring high on either the Chapman Perceptual Aberration Scale or the Raine Schizotypal Personality Questionnaire produce pursuit tracking records with significantly lower quality than those produced by normal controls. The present study extends the earlier investigations by utilizing a substantially larger group of questionnaire-identified at-risk persons, using quantitative measures of pursuit tracking, and including a group identified on the basis of their self-report of social anhedonia. We observed that the at-risk groups displayed significantly poorer smooth pursuit eye tracking, as measured by higher RMSE scores and lower gain scores, than normal control subjects. Thus, we replicated the findings of Lencz et al. (1993) and O'Driscoll et al. (1998) using quantitative measures of eye tracking. The psychosis-prone groups also had a greater proportion of subjects who exhibited deviant eye tracking.

To our knowledge, this study is the first to assess pursuit tracking performance in three groups of questionnaire-identified at-risk subjects. The investigation of Simons and Katkin (1985) included high scorers on the PhysAnh Scale and high scorers on the Perceptual Aberration Scale. Although Simons and Katkin reported negative findings, they also indicated that a subset of the participants produced deviant records. Similar to Simons and Katkin (1985), we also identified a group of individuals whose pursuit eye tracking was impaired. Moreover, we detected significant differences between the at-risk and control subjects.

Our investigation also allowed us to compare the pursuit performance of three different groups of at-risk subjects. Contrary to our expectations, subjects who endorsed negative-symptom schizotypy (the SocAnh and PhysAnh groups) did not produce significantly poorer tracking than the subjects who endorsed items suggestive of positive-symptom schizotypy (the Per-Mag group). This finding is intriguing, given prior indications (cf. Siever et al., 1994) of an association between impaired tracking and deficit-like symptoms in patients with schizotypal personality disorder, as well as an association between impaired tracking and negative symptoms in patients with schizophrenia (cf. Katsanis and Iacono, 1991). The reason for our findings, which are based on putatively at-risk subjects, appearing less robust than those derived from patient samples is not wholly clear. However, our findings are consistent with the heterogeneity that characterizes groups of individuals who score deviantly high on the Chapman psychosis-proneness Scales. Further evidence for this heterogeneity comes from our observation that among the PhysAnh group, 50% (16 of 31) could have been reclassified as Per-Mag or SocAnh individuals on the basis of their second highest score.

Consistent with prior studies of normal controls and schizophrenia patients (cf. Gooding et al., 1997), we observed a high correlation between our two quantitative measures of pursuit tracking, namely, RMSE scores and gain. Given the psychometric properties of RMSE (Clementz et al., 1996), we relied upon that measure for the remainder of the analyses reported. Nonetheless, it is significant that the at-risk subjects differed from the controls not only in terms of a global quantitative measure, but also in terms of another measure, namely, gain. Contrary to our hypotheses, neither total number of saccades nor total number of anticipatory saccades significantly differentiated eye tracking performance among the questionnaire-identified at-risk subjects and control subjects. This negative finding is consistent with the results of Siever et al. (1994), who also noted the failure of saccadic measures to differentiate between the experimental and control groups.

Although neither the at-risk subjects nor the control subjects displayed a significant association between pursuit performance and psychotic-like experiences, the psychotic-like experiences that were examined in this investigation were wholly positive symptoms, i.e. perceptual anomalies and mild delusional thinking. This finding is consistent with the notion that deviant pursuit eye tracking is a trait characteristic, independent of clinical status. It is not clear whether an interview-based assessment of the negative aspects of schizotypal symptomatology would have yielded an association with tracking performance. This possibility is particularly intriguing, given indications from a twin study of schizotypy (Kendler et al., 1991) that negative symptom schizotypy was related to trait anhedonia and eye tracking error, though clinically rated positive symptom schizotypy was not related to eye tracking error.

We replicated earlier findings (cf. Allen et al., 1987) that individuals with deviant scores on the Perceptual Aberration and/or Magical Ideation Scales report more severe psychotic-like experiences than controls. Interestingly, we observed that individuals with deviant scores on the revised Social Anhedonia Scale also reported more deviant psychotic-like experiences compared to normal controls, though they did not appear as deviant as the group endorsing perceptual anomalies and magical ideation. These findings are intriguing, given prior observations (cf. Kwapil et al., 1997) that individuals with elevated scores on both Social Anhedonia and Magical Ideation appear at particularly high risk for subsequent development of schizophrenia.

To our knowledge, this is the first study to report on visual fixation performance in questionnaire-identified at-risk individuals. We observed a relatively small but significant correlation between performance on the smooth pursuit tracking task and visual fixation performance. Despite this, the groups did not differ significantly in their performance on the fixation tasks. On average, all the subjects made one saccade during a 30-s epoch of fixation. These results suggest that visual fixation, as assessed in this study, is not likely to serve as a biobehavioral indicator of risk in questionnaire-identified samples.

It is noteworthy that our questionnaire-identified at-risk subjects were relatively young and high functioning. It remains possible that aberrant visual fixation would be observed in cognitively and functionally impaired schizotypal subjects. Most of the present sample had also been administered an antisaccade task; the antisaccade task is considerably more difficult than the fixation task, though both tasks involve the inhibition of saccades. Correct performance of the antisaccade task involves the inhibition of a prepotent reflexive saccade and the generation of a purposeful saccade in the opposite direction. Both the Social Anhedonia group and the Per-Mag group displayed aberrant performance on the antisaccade task relative to controls (Gooding, 1999). It is possible that the fixation task did not differentiate the groups because the task did not sufficiently tax the oculomotor system. The observed antisaccade task deficits in questionnaire-identified at-risk individuals, considered along with the present results, suggest that in at-risk populations prior to the manifestation of overt psychopathology, tasks with a greater cognitive load are required before deficits can be observed.

To summarize, a subset of subjects with extreme scores on the Chapman Scales also displayed deviant smooth pursuit eye tracking; these individuals are hypothesized to be at heightened risk for the development of schizophrenia. Given the assertion (cf. [Miller and Yee, 1994] and [Gooding and Iacono, 1995]) that the psychometric high-risk method combined with a biobehavioral high-risk approach may improve the prediction rate of individuals at heightened risk for the manifestation of schizophrenia, suggested future directions would include longitudinally following the at-risk individuals and empirically testing the predictive value of the combined use of risk indicators.

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