

---

# The misclassification of blinks as saccades: Implications for investigations of eye movement dysfunction in schizophrenia

---

MONICA E. CALKINS,<sup>a</sup> JOANNA KATSANIS,<sup>b</sup> MICAH A. HAMMER,<sup>a</sup>  
AND WILLIAM G. IACONO<sup>a</sup>

<sup>a</sup>Department of Psychology, University of Minnesota, Minneapolis, USA

<sup>b</sup>Department of Psychiatry, University of Arizona, Tucson, USA

## Abstract

It is important to have a simple, accurate method for recording eye movements. Of the two popular approaches commonly adopted, electro-oculography (EOG) and infrared oculography (IROG), IROG is often accepted as the more accurate, and it is the method that is currently used most frequently to examine eye movements in schizophrenia. This study investigated whether the misclassification of blinks as saccades affects saccade rates when the presence of a blink is determined using only IROG recordings of eye position. Both vertical electro-oculography (VEOG), which can be used to objectively identify blinks, and IROG were recorded while 17 schizophrenia patients and 19 healthy controls were presented with sinusoidal stimuli. Of the blinks identified with the VEOG for the total group of participants, a substantial number (37%) were misclassified as catch-up and anticipatory saccades when only the IROG was used. Furthermore, in the schizophrenia group, but not in the healthy control group, the use of the IROG led to a significant misclassification of blinks as anticipatory saccades. Therefore, when IROG alone is used to identify blinks, the misclassification of blinks as saccades is likely to introduce measurement error into estimates of saccade rates, particularly estimates of anticipatory saccade rates in schizophrenia patients.

**Descriptors:** Schizophrenia, Eye movement dysfunction, Eye movement methodology, Blink identification, Infrared oculography, Vertical electro-oculography

There is substantial evidence that a deficit in smooth pursuit functioning is an endophenotypic marker of schizophrenia, that is, a measurable endogenous characteristic that results from the genotype that predisposes an individual to psychopathology (Iacono, 1988). Smooth pursuit tracking proficiency can be quantified using various techniques, most of which are intended to characterize the quality of the smooth component of the tracking response or the nature of the saccadic eye movements that are interspersed with segments of smooth pursuit. Because the brain mechanisms gov-

erning both types of eye movement are separate but work together to keep the eyes on target in a smooth tracking task, accurate quantification of both types of eye response may provide useful insight into the etiology of this dysfunction in schizophrenia. In this report, we show how a known artifact, the eye blink, can unknowingly interfere with the accurate measurement of one of these two constituent eye movements, the saccades that occur during pursuit tracking.

Although early reports of tracking dysfunction in schizophrenia relied on electro-oculography (EOG) to monitor ocular motion, infrared oculography (IROG) has now become the dominant recording technique. This shift has been motivated in part by the fact that IROG is free of the biopotential artifact common to EOG recording (Iacono & Lykken, 1981), thus allowing for more precise measurement of small saccades. We identified 86 studies of smooth pursuit in schizophrenia that have been conducted using IROG to record ocular motion. IROG detects horizontal eye movements via a pair of phototransistors positioned on either side of an infrared light emitting diode (LED) that are arranged horizontally in front of the eye and usually mounted on spectacles. The LED illuminates the surface of the eye, and because the sclera is more reflective and sharply distinct from the iris, as the eye position changes, the phototransistors produces a voltage proportional to the intensity of the light reflected back (Kumar & Krol, 1992).

---

This project was completed in partial fulfillment of the requirements for the Master's degree of the first author, and was supported by a NIMH Neurobehavioral Traineeship (MH 17069) to the first author, by NIMH Grant MH 49738, and by a NARSAD Young Investigator award to the second author. Preliminary results from this investigation were presented at the Seventh International Congress on Schizophrenia Research, Santa Fe, NM, April 17–21, 1999. The authors thank William M. Grove, who provided helpful feedback on earlier versions of the manuscript, Clay Curtis, Kate Delaney, Kathy Feil, Joanna Fiszdon, Amy Hallberg, Dave Lake, Boyd Lebow, John Pina, and Beth Snitz for their hard work in recruiting and assessing study participants, and the individuals who participated in this study. The authors also thank Sam Hutton for his helpful suggestions.

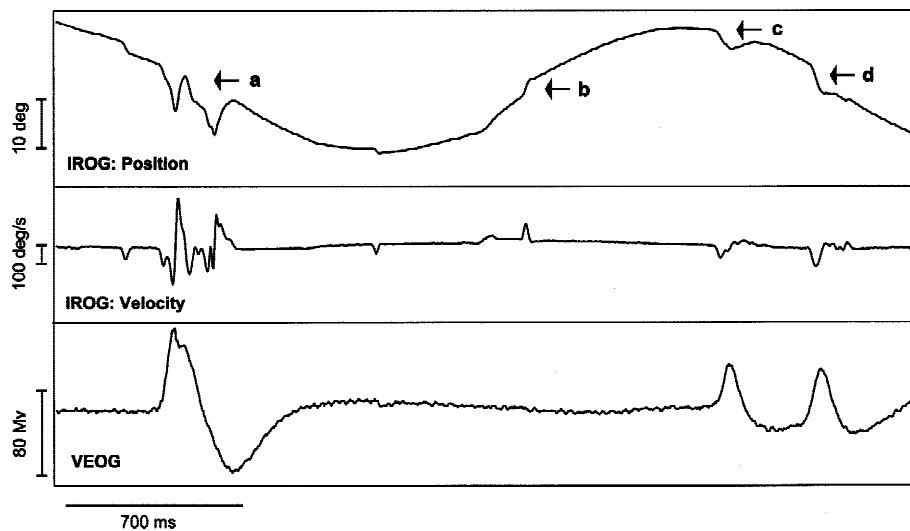
Address requests for reprints to: William G. Iacono, Clinical Science and Psychopathology Research Training Program, Department of Psychology, University of Minnesota, Elliott Hall, 75 East River Road, Minneapolis, MN 55455-0344, USA. E-mail: wiacono@tfs.psych.umn.edu.

Blinks can produce profound artifacts in IROG records (Iacono & Clementz, 1992), but investigators using only IROG frequently do not mention the procedure used to identify blinks. Of 73 investigations of smooth pursuit in schizophrenia using only IROG that were located in the literature, only 20 provide any information regarding how blinks were identified. Of those that do provide such information, morphological features related to the appearance of a blink in the IROG position recording, such as spikiness and polarity reversals, are typically used to identify blinks. Only two research teams described blink identification procedures based on criteria other than presumed morphology. Moser, Kompf, Arolt, and Resch (1990) relied on amplitude and velocity features, but did not specify how this information was used to identify a blink. Radant, Hommer and colleagues reported a biphasic velocity criterion based on preliminary studies, presumably using IROG only, in which subjects were instructed to blink (e.g., Radant & Hommer, 1992). In later studies, these investigators implied, however, that they used visual inspection of the position data to verify that segments identified using the velocity criteria were saccades (e.g., Litman, Hommer, Radant, Clem, & Pickar, 1994).

In our laboratory, we record IROG and vertical electro-oculography (VEOG) concurrently. VEOG, measured from electrodes placed above and below one eye, measures the changes in the corneoretinal potential that arise from the "rider artifact" generated by the movement of the lid over the eyeball. VEOG provides a simple and valid method for identifying blinks (e.g., Clarkson & Berg, 1984; Stern, Walrath, & Goldstein, 1984). We informally observed that blinks identified by VEOG do not always appear in the IROG record with the typical spikiness or polarity reversal, and indeed sometimes appeared to be, or masqueraded as, saccades. For example, Figure 1 depicts the IROG and the corresponding VEOG tracings from one research participant. The first event (a), identified by the VEOG as a blink-contaminated segment, manifests in the IROG record with the characteristic spikiness and

polarity reversal of blinks that have been described in the literature. The third (c) and fourth (d) events, however, do not exhibit this characteristic morphology in the IROG record, although the VEOG record indicates that the segments are coincident with blinks. When only the IROG record is relied on, the fourth segment (d) appears to be a saccade, although it is blink contaminated. The second event (b) provides an example of a true saccade; note that there is no discernible deflection in the corresponding section of the VEOG signal (see Figure 1). Blink-contaminated segments are thus IROG segments in which a blink artifact is mistaken as a saccade or in which a blink and saccade occur together with the blink artifact possibly distorting the recording of the saccade in a manner that cannot be determined. It is because blinks distort the IROG that investigators attempt to exclude blink contaminated segments from analyses, but this case example indicates that the IROG alone may sometimes be distorted in such a way as to prevent the differentiation of blink-contaminated segments from pure eye movements. Only a handful of schizophrenia research teams have used VEOG contemporaneously with IROG (e.g., Ross et al., 1997; Schmid-Burgk, Becker, Diekmann, Jurgens, & Kornhuber, 1982; Whicker, Abel, & Dell'Osso, 1985). Consequently, it is possible that for many published IROG studies, error has been introduced into the identification and measurement of saccades.

Because several reports have indicated that patients with schizophrenia evince increased blink rates compared with healthy controls during smooth pursuit (e.g., Amador et al., 1991), it is possible that the observed group differences in saccade rates are affected by this methodological problem. Furthermore, it has been suggested that the neural mechanisms involved in the generation of blinks interact with those implicated in the initiation of saccadic eye movements (Leigh & Zee, 1999). Indeed, there is evidence to suggest that there is a blink-saccade synkinesis, as a result of which blinks accompany large saccades when they occur in a gaze shift (Sibony & Evinger, 1998). The evidence for a blink-saccade



**Figure 1.** Sample infrared (IROG) (position and velocity) and the corresponding vertical electro-oculography (VEOG) tracings from one participant tracking a 0.4-Hz sinusoidal target. The first blink-contaminated segment (a) manifests the characteristic spikiness and polarity reversal in the IROG position and velocity tracings and is correctly identified as a blink when only the IROG is used. The third (c) and fourth (d) segments do not exhibit the characteristic blink morphology in the IROG position or velocity tracings. The fourth labeled, blink-contaminated segment (d) appears in the IROG position tracing to be a pure saccade. The corresponding velocity tracing does not exhibit a polarity reversal that would assist in blink identification. The segment marked b provides an example of a true saccade; note that there is no discernible deflection in the corresponding section of the VEOG signal.

synkinesis and the possibility that some blinks are misclassified as saccades, as in Figure 1, suggest a potential problem with the use of only IROG position data to assess eye movements in paradigms designed to elicit saccadic eye movements. That is, it may be that blinks that occur simultaneously with, or immediately preceding, saccades could be missed if the VEOG is not utilized. Consequently, in saccadic paradigms, such as antisaccade and prosaccade tasks, estimates of saccade accuracy, duration, velocity, and reaction time could be compromised when blinks contaminate the saccade.

In this study, we first investigated how frequently blinks identifiable by use of VEOG would be misclassified as saccades in a smooth pursuit paradigm when only IROG position records and standard morphological criteria were used. Second, we investigated whether these misclassifications were likely to masquerade as particular subtypes of saccades. Third, we sought to determine whether the misclassification of blinks as saccades differentially affected group frequencies of each saccade subtype.

## Method

### Participants

The participants were 19 healthy control individuals (6 men) and 17 psychiatric inpatients (13 men) with a diagnosis of schizophrenia based on the Structured Clinical Interview for DSM-IV (SCID) and chart review. The mean ages for controls and patients were 32.7 ( $SD = 11.2$ ) and 35.2 ( $SD = 9.1$ ), respectively; the ages did not significantly differ,  $t(34) = .68$ , n.s. The participants were a subset drawn from a larger sample that participated in an extensive test battery. The method of participant selection is presented in detail in Curtis, Calkins, Grove, Feil, and Iacono (2001).

### Procedures

The recording of eye movements was conducted in a quiet, dimly lit room. Eye movements were assessed monocularly (right eye) using an Applied Science Laboratories (Eyetrac Model 210) infrared (IR) monitor, which has a time constant of 4 ms and a bandwidth of 250 Hz, mounted on eyeglass frames. Sensors were positioned according to manufacturer specifications (Applied Sciences Laboratory, 1984). Participants' heads were stabilized throughout the procedure by a dental bite bar to minimize head movement artifact. Contact lenses, if worn, were removed prior to each session to minimize artifact and eye dryness. A computer monitor was used to present the stimulus. The VEOG recordings were obtained from the superior and inferior orbital rims of the left eye with a shin ground. Electrode impedances were required to be below 10 k $\Omega$  for each participant. VEOG signals were conditioned at a low frequency cutoff of 0.1 Hz and a high frequency cut-off of 1 Hz. Data were digitized off-line at a sampling rate of 256 Hz.

The stimulus was a 0.5 deg yellow circle, within which there was a small dot subtending a few minutes of visual arc; the circle traversed the screen horizontally in a sinusoidal fashion at a rate of 0.4 Hz. Before task commencement, the IR signal was calibrated individually for each participant so that the stimulus traversed  $\pm 10$  deg of visual angle. The participants were instructed to refrain from blinking, keep their heads still and their mouths on the bite bar as they watched the dot for 12 cycles of sinusoidal pursuit. Throughout the task, the experimenter monitored the signals, which were displayed both by computer monitor and ink writer oscillograph, from an adjoining room. This task was part of a larger battery of eye tracking tasks administered to the participants within

the testing period and was the first task completed by each participant following a brief practice trial.

### Data Processing

**Blink identification.** Two raters (JK and MH), blind to the diagnostic status of the participants, identified blinks using only the record of the infrared (IROG) position tracing. Consistent with past research, blink identification using IROG records was based on the characteristic morphology of blinks. Specifically, events were classified as blinks when they evidenced large amplitude spikes or a distinctive reversal in polarity in the position tracing (see Figure 1 at point a). These ratings were characterized as the IROG only blink ratings. The Pearson  $r$  for number of blinks identified per participant by the two raters was .92 ( $p < .001$ ). A third rater (MC), blind to the participants diagnostic status, identified blinks using both the IROG and VEOG (VEOG rating). The IROG was provided to the VEOG rater to ensure that blinks were only counted during eligible segments of the IROG record (i.e., discarding the first and last cycles of participants tracking, and any segments in which the participant was not engaged in the task). Blinks were identified as biphasic segments of the VEOG record that exceeded 50  $\mu$ V according to the criteria established by Tecce, Savignano-Bowman, and Kable (1978). The blinks identified using the VEOG were considered the "gold standard" for the occurrence of blinks.

**Saccade identification and classification.** One of the two IR only raters (MH), who was also blind to the hypotheses of the study, identified and classified all saccades in the subject's record, again using only the IROG position tracing. There is variability across research teams in the criteria used to identify saccades, but there are some key components that most criteria share. Consequently, we chose criteria that were representative of these components and that were similar to the empirically derived criteria of Friedman et al. (1992). Catch-up saccades (CUS) were defined as eye movements that took the eyes away from a position behind the target to a position on or near the target, were preceded by at least 40 ms of pursuit, and were  $< 5$  degrees in amplitude. Back-up saccades (BUS) were eye movements that took the position of the eye from ahead of the target back to the target, or took the eyes from the target to a position behind the target. Anticipatory saccades (AS) were eye movements that occurred in the direction of target motion, moved the position of the eye from the target to a position ahead of the target, and that exceeded 5 deg in amplitude. Square-wave jerks (SWJ) were a pair of saccades, preceded and followed by pursuit, with an intersaccadic interval of 80 to 450 ms, both saccades of which were  $< 5$  deg in amplitude.

## Results

### Data Analyses

The analyses of the data were conducted in four steps. First, we quantified the extent to which blinks were accurately identified when only IROG records were used. Second, we calculated the percentages of misclassifications of each saccade subtype as blinks. A misclassification was defined as any event that was identified as a blink using the VEOG but that was classified as a saccade when only the IROG was used. These events include blinks occurring alone and may include blinks that are accompanied by saccades. When blinks occur simultaneously with saccades, and only the IROG record is used, it is impossible to distinguish which part of the event represents the saccade and which the blink. For this

reason, most investigators eliminate IROG segments that appear to include blinks. Third, we compared the characteristics of blinks that were misclassified as pure saccades with the characteristics of true saccades to determine whether there were any features that would enable IROG users to better differentiate saccades from blinks. Finally, group differences in saccade rates, both corrected and uncorrected for misclassified blinks, were examined.

Because the distributions of several of the variables violated the assumption of normality (as determined by small significance levels of the Lilliefors test) upon which parametric statistics are based, the Mann–Whitney U test was used to estimate group differences, except where otherwise indicated. All comparisons that were significant with nonparametric statistics were also significant using parametric statistics. Effect sizes ( $d$ ) were calculated using the sample size-weighted pooled within-group standard deviation to provide estimates of group differences independent of sample size (Hunter & Schmidt, 1990).

Saccade counts were corrected for the number of blinks that were misclassified as saccades. The correction consisted of first identifying each event that was rated as a blink when the VEOG was used but not when only the IROG was used to identify blinks (we conservatively considered here only blinks that both raters using only IROG failed to identify). Next, we determined whether each such event had been classified as a saccade, and if so, as which type of saccade. We then subtracted the blinks that were misclassified as saccades from the appropriate saccade counts for each participant. The number of true saccades per second (i.e., saccade rate) was then calculated for each saccade subtype. The data from the first and last cycles were excluded from analysis, as were any segments in which a participant was not engaged in the task (i.e., as indicated by notes on the oscillograph charts provided by the psychophysicist at the time of data collection or by segments of at least one half cycle during which the IROG position tracing failed to approximate a sinusoidal wave).

### Blinks

A total of 111 blinks in the records of the 36 participants were identified with the use of the VEOG. Of these blinks, only 59% ( $n = 65$ ) were identified as blinks when only the IROG was used; in other words, 41% ( $n = 46$ ) of the blinks identified using the VEOG were missed when only the IROG was used. No events were classified by both IROG raters as a blink that were not identified as a blink by the VEOG. The use of VEOG records allowed for the identification of significantly more blinks per second than did the use of the IROG records alone, Wilcoxon Matched-Pairs Signed-Rank Test,  $z = -3.53$ ,  $p < .0004$ , Cohen's  $d = 0.80$ ; VEOG  $M = 0.12$ ,  $SD = 0.15$ ; IROG only  $M = 0.01$ ,  $SD = 0.13$ ;  $z = -2.1$ . The blink rate as determined by the VEOG did not significantly differ between schizophrenia patients,  $M = 0.13$  blinks per second,  $SD = 0.16$ , and controls,  $M = 0.12$ ,  $SD = 0.14$ ,  $z = -0.032$ , n.s., Cohen's  $d = 0.07$ . The blink rate as determined by the IROG only was also not significantly different between the two groups, schizophrenia  $M = 0.01$ ,  $SD = 0.16$ ; control  $M = 0.01$ ,  $SD = 0.11$ ,  $z = -0.36$ , n.s., Cohen's  $d = 0$ .

### Saccades

A total of 1,538 saccades were identified across the 36 participants using the IROG (all events identified as saccades were classifiable as follows: 85% were CUS, 7% were BUS, 6% were AS, and 2% were SWJ). A substantial percentage ( $n = 41$ , 37%) of true blinks (i.e., those identified with the VEOG) was misclassified as saccades when only the IROG was used. The majority of the misclas-

sified blinks appeared as CUS (24%), whereas the remainder appeared as AS (5%). No blinks were misclassified as SWJ or BUS (0%). A small percentage (13%) of blink events was classified as neither blinks nor saccades by the IROG only. An illustration of these outcomes is provided in Figure 1. Relying exclusively on the IROG position tracing, point a marks a blink-contaminated segment that was identified correctly, b is a true CUS, c denotes an event classified as neither a blink nor a saccade, and d indicates a putative CUS. Inspection of the VEOG record indicates that events marked c and d both reflect blink artifact.

Because the saccade subtypes differ in their frequency, it is useful to consider the differential effect that misclassification had on each subtype. Table 1 presents the frequency data of each subtype as identified using only IROG (i.e., before correction for misclassified blinks) and with IROG plus VEOG (i.e., after correction for misclassified blinks), as well as the percentage of each saccade subtype that was misclassified as blinks. Although the impact of misclassification was minimal for total saccade frequencies and for most saccade subtypes, a relatively large percentage of events classified as AS using only the IROG were actually blinks (see Table 1).

We next examined whether there were any characteristics of the misclassified blinks that could be relied upon by users of only IROG to distinguish them from true saccades. Specifically, from the digitized IROG records, we obtained the velocity and acceleration of blinks that were misclassified as AS, blinks misclassified as CUS, and a random selection of true AS ( $n = 15$ ) and true CUS ( $n = 27$ ). The mean and median velocity and acceleration were calculated from the interval between the initiation of the eye movement and its endpoint. Mann–Whitney U tests revealed that none of these variables significantly differentiated blinks that were misclassified as AS and true AS, mean velocity  $z = -0.16$ , Cohen's  $d = 0.31$ ; median velocity  $z = -0.07$ , Cohen's  $d = -0.11$ ; mean acceleration  $z = -1.03$ , Cohen's  $d = 0.28$ ; median acceleration  $z = -0.48$ , Cohen's  $d = 0.15$ ; all  $p$ 's  $> .05$ . Similarly, true CUS and blinks that were misclassified as CUS did not significantly differ in mean velocity, median velocity, mean acceleration, or median acceleration, mean velocity  $z = -1.91$ , Cohen's  $d = -0.36$ ; median velocity  $z = -0.47$ , Cohen's  $d = 0.03$ ; mean acceleration  $z = -0.94$ , Cohen's  $d = 0.39$ ; median acceleration  $z = -1.02$ , Cohen's  $d = -0.05$ ; all  $p$ 's  $> .05$ . Thus where blinks manifest as AS and CUS in the IROG record, they cannot be distinguished from true AS and CUS, respectively, on the basis of their velocity or acceleration.

**Table 1.** Frequency of Saccade Subtypes Before and After Correction for Blinks Misclassified as Saccades

Saccade type	Number of saccades before correction for misclassified blinks (IROG rating)	Number of saccades after correction for misclassified blinks	Percentage of "saccades" that were actually blinks
All saccades	1,538	1,497	2.7
Catch-up saccades	1,301	1,274	2.1
Back-up saccades	110	110	0
Anticipatory saccades	95	81	14.7
Square-wave jerks	32	32	0

Note: Data are from total group ( $n = 36$ ).

Table 2 presents the results of the analyses of mean saccade rates before and after correction for blinks that were misclassified as saccades. As the right-most columns of the table indicate, the patients had significantly higher total saccade and CUS rates than the comparison group both before and after blink correction. An additional set of analyses was carried out for each group to determine whether saccade counts were significantly reduced following the VEOG correction. With one exception, for both patients and controls, the rates of total saccades, AS, and CUS, were significantly lower when the blinks that were misclassified as saccades were removed from the saccade tally, all  $z$ 's  $< -2.06$ ,  $p$ 's  $< .05$ . The one exception involved the controls and AS; the removal of blinks misclassified as AS did not significantly affect the AS rate for controls,  $z = -1.63$ ,  $p = n.s.$ . Thus, the misclassification of blinks as AS led to a significant increase in the observed rate of events categorized as AS in the schizophrenia patients, but not in the controls.

### Discussion

The results of this investigation indicate that when standard morphological criteria are used to identify blinks, a substantial percentage of blinks (41% of those evidenced in this sample) that were identifiable with VEOG were not identifiable when only IROG was used. Furthermore, approximately one-third (37%) of blinks were misclassified as saccadic eye movements when only IROG was employed. These blinks masqueraded as AS and CUS; no blinks were misclassified as BUS or SWJ. Where blinks manifest as saccades in the IROG record, they cannot be distinguished from pure saccades on the basis of their velocity or acceleration. Within the schizophrenia and control groups, the use of the IROG led to the misclassification of a significant number of blink-contaminated segments as total saccades and CUS. Furthermore, in the schizophrenia group, but not in the healthy control group, the use of the IROG led to a significant misclassification of blinks as AS.

Several previous reports have suggested that schizophrenia patients' evidence increased blink rates during smooth pursuit compared with healthy controls (e.g., Amador et al., 1991). The results of this investigation suggest that in samples in which schizophrenia patients blink more frequently than controls, and in

which only IROG is used to assess eye movements, estimates of group differences in saccade rates are likely to be affected. In particular, AS rates in schizophrenia patients appear to be most vulnerable to the effects of blink misclassification. The participants in this study, from whom these data were derived, were instructed to refrain from blinking and performed the task at the beginning of the eye tracking battery. Consequently, they were tested under optimal conditions in which they were unlikely to be fatigued or bothered by significant eye dryness from the IROG, and so less likely to produce extraneous blinks (Iacono & Lykken, 1983). Investigators do not typically report that they have instructed their participants not to blink. Thus, this investigation is likely to have underestimated the effects of blinking on group differences when only IROG is used.

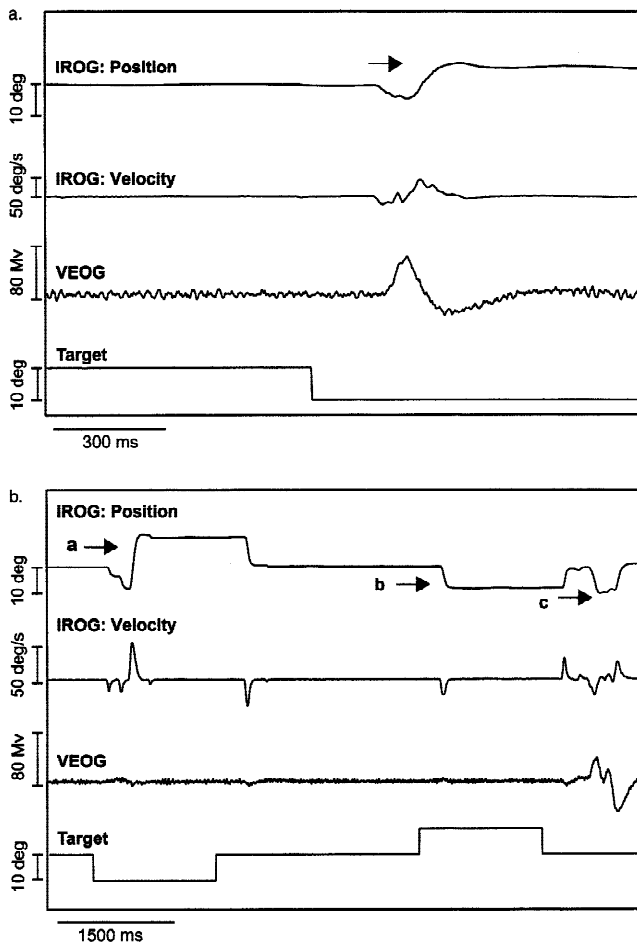
In the current investigation, we employed the widely used 5-deg minimum amplitude criteria for the identification of AS. Blinks are typically large amplitude events, and it is intuitive that such large amplitude events could most readily masquerade in the IROG as large amplitude eye movements, such as AS as they were defined in the present study. Recent work by Ross, Olincy, and Radant (1999) suggests that differences between the AS rates of schizophrenia patients and healthy controls are greater and more consistent when amplitudes of 1–4 deg are used as criteria for identifying AS than when amplitudes of 4 deg or greater are employed. Therefore, AS that are defined as smaller than 5 deg may not only have greater construct validity as Ross et al. contend, but they may also be less vulnerable to the effects of blink misclassification.

Although our results pertain specifically to smooth pursuit tracking tasks, other data from our lab suggest that tasks designed to elicit saccades may also be subject to blink artifact. Illustrations of cases in which this could occur are presented in Figures 2 and 3. Both are records from an antisaccade task in which the participant is instructed to generate a saccade in the direction opposite that of target motion. Figure 2, upper panel, illustrates that when the IROG is used alone, a blink contaminated segment could appear as an incorrect saccade to the target; inspection of the VEOG indicates that the participant actually blinked at the outset of the trial, calling into question whether a prosaccade error was executed (see Figure 2). Event (a) in the lower panel of Figure 2

**Table 2.** Saccade Rates Before (IROG only) and After (VEOG) Correction for Blinks That Were Misclassified as Saccades

	Patients ( $n = 17$ )	Controls ( $n = 19$ )	$z$	$p$	$d$
Total saccades					
IROG only (#/s)	2.06 ± 0.74	1.40 ± 0.58	-2.62	.009	0.99
IROG plus VEOG (#/s)	2.00 ± 0.74	1.36 ± 0.56	-2.68	.007	0.98
Catch-up saccades					
IROG only (#/s)	1.79 ± 0.74	1.13 ± 0.52	-2.69	.007	1.04
IROG plus VEOG (#/s)	1.75 ± 0.74	1.11 ± 0.51	-2.66	.008	1.02
Anticipatory saccades					
IROG only (#/s)	0.11 ± 0.15	0.10 ± 0.16	-0.90	.366	0.06
IROG plus VEOG (#/s)	0.10 ± 0.13	0.08 ± 0.14	-0.66	.508	0.15
Back-up saccades					
IROG plus VEOG (#/s)	0.11 ± 0.10	0.13 ± 0.13	-0.30	.760	-0.17
Square-wave jerks					
IROG plus VEOG (#/s)	0.04 ± 0.06	0.03 ± 0.05	-0.58	.563	0.03

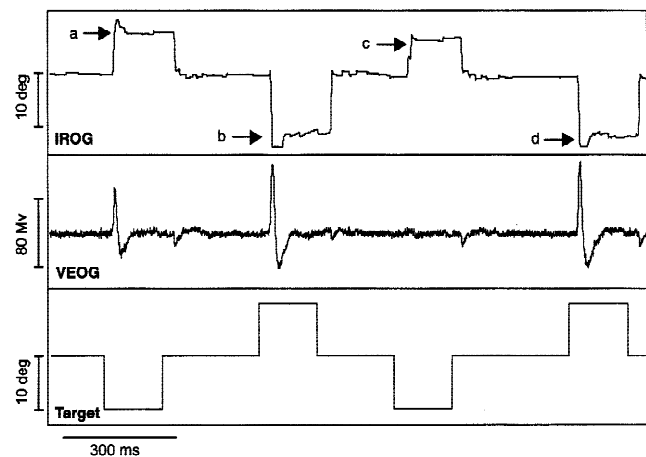
Note: #/s = number of saccades per second of tracking. Values are means ± standard deviations.



**Figure 2.** Recordings of IROG, VEOG, and the target obtained during an antisaccade task, in which the participant is required to generate a saccade in the direction opposite that of target motion. Upper panel: The IROG position tracing alone suggests that the participant produced a prosaccade error to the target at the point demarcated by the arrow. Inspection of the VEOG indicates that the participant blinked at the outset of the trial, calling into question whether a prosaccade error was executed. The corresponding velocity tracing exhibits some bipolarity. Lower panel: (a) An example of an incorrect prosaccade to the target, followed by a corrective saccade, that is unaccompanied by a blink, as indicated by the VEOG tracing, but demonstrates bipolarity in the velocity tracing. Event (b) is an uncontaminated correct antisaccade. Event (c) is a blink-contaminated event provided for comparison with Events (a) and (b).

is an incorrect prosaccade to the target, followed by a corrective saccade. Unlike the event in the upper panel, this event is not contaminated by a blink, as indicated by the VEOG, but is accompanied by a similar velocity profile. Event (b) is an uncontaminated correct antisaccade. Event (c) is a blink-contaminated event provided for comparison with Events (a) and (b).

Figure 3 demonstrates how undetected blinks can affect measures of amplitude and reaction time. Three of four correct antisaccades (labeled a, b, and d) are accompanied by blinks, as indicated by the VEOG. The first saccade (a) appears in the IROG to be a valid antisaccade from which amplitude and latency information could be obtained; however, the VEOG indicates that the entire saccade is concurrent with a blink. It could perhaps be argued that the segment of the IROG record at the initial peak of



**Figure 3.** Recordings of IROG, VEOG, and the target obtained during four consecutive trials of an antisaccade task performed by a relative of a schizophrenia patient. Three of these correct antisaccades (labeled a, b, and d) are accompanied by blinks, as indicated by the VEOG. The first saccade (a) appears in the IROG to be a valid antisaccade from which amplitude and latency information could be obtained; however, the VEOG indicates that the entire saccade is overlapped by a blink. The appearance in the IROG of the second (b) and fourth (d) antisaccades is ambiguous; without the use of the VEOG, the events might be correctly recognized as including clipped blinks, or incorrectly identified as solely large amplitude saccades that are clipped or followed by periods of fixation. The third antisaccade (c), is unaccompanied by blink.

this antisaccade is indicative of a blink, but the corresponding peak in the record of the third antisaccade (c), which is unaccompanied by a blink, appears very similar in the IROG record. The appearance in the IROG of the second (b) and fourth (d) antisaccades is ambiguous: without the use of the VEOG, the events might be correctly recognized as including clipped blinks, or incorrectly identified as solely large amplitude saccades that were either clipped or followed by brief periods of fixation (see Figure 3). Consequently, depending on the judgment call of a researcher using only IROG records, the characteristics of such events could contaminate estimates of the latency and amplitude of antisaccades.

The IROG recording system (Eye Trac Model 210, Applied Science Laboratories) that was used in this investigation has 4-ms temporal resolution (corresponding to a maximum sampling rate of 250 Hz), whereas some other systems allow for better resolution if data are sampled at rates above 250 Hz. Whether better resolution could be used to substantially improve blink identification remains an open empirical question. However, the Eye Trac 210 has been the most widely used apparatus for the study of schizophrenia smooth pursuit. Of 58 studies in this area in which the eye movement recording system was reported, 31 employed the Eye Trac 210, and an additional 17 used systems with similar or slower sampling rates. Systems such as the Ober2, which can sample at 1000 Hz, have been used in only a few investigations (e.g., Chen et al., 1999; Jacobsen, Hommer, et al., 1996; Jacobsen, Hong, et al., 1996).

One research team has used bipolarity in the velocity tracing to identify blinks (e.g., Radant & Hommer, 1992). The events depicted in Figures 1 and 2 suggest that such criteria may be unable to identify certain blinks that manifest as saccades in the IROG. However, biphasic velocity criteria were not used in the present investigation and as such it is unknown whether biphasic velocity

criteria lead to similar rates of misclassification as morphological position criteria. Binocular IROG recordings might assist IROG users in the identification of blinks; in previous investigations in our laboratory in which we have collected binocular IROG and VEOG, we have observed events in which the blink (as determined by the VEOG) was evident in one channel of the IROG but not the other. We have, however, also observed occasions in which the blink (as determined by the VEOG) appeared as a saccade in both IROG channels (examples are available upon request from the authors). Thus, although it is possible that binocular recordings may reduce the number of misclassifications, this question should be addressed by future investigations with VEOG and binocular IROG.

In conclusion, the present study investigated one methodological variable that could potentially account for the variability evi-

denced in rates of saccade subtypes in the schizophrenia literature. We do not claim that all IROG recording systems are incapable of identifying blinks or that the only way to identify blink artifacts is through VEOG. Rather, we believe that our results indicate that studies that use commonly employed IROG techniques and that rely on IROG position data to identify blinks (as dozens of studies in this literature do) are misclassifying blinks as saccades. This misclassification is likely to affect estimates of differences in rates of saccade subtypes (especially AS and CUS) between patients with schizophrenia and healthy controls when, as is often the case, schizophrenia patients blink more than controls. Finally, empirical investigations are required to determine the extent to which the results of studies using IROG to assess eye movements during saccadic paradigms are vulnerable to contamination by blink misclassification.

## REFERENCES

- Amador, X. F., Sackeim, H. A., Mukherjee, S., Halperin, R., Neeley, P., Maclin, E., & Schnur, D. (1991). Specificity of smooth pursuit eye movement and visual fixation abnormalities in schizophrenia: Comparison to mania and normal controls. *Schizophrenia Research*, *5*, 135–144.
- Applied Science Laboratories (1984). *Model 210 Eye Movement Monitor: Operation and Service Manual*. Author.
- Chen, Y., Levy, D. L., Nakayama, K., Matthyse, S., Palafox, G., & Holzman, P. S. (1999). Dependence of impaired eye tracking on deficient velocity discrimination in schizophrenia. *Archives of General Psychiatry*, *56*, 155–161.
- Clarkson, M. G., & Berg, W. K. (1984). Bioelectric and potentiometric measures of eyeblink amplitude in reflex modification paradigms. *Psychophysiology*, *21*, 237–241.
- Curtis, C. E., Calkins, M. E., Grove, W. M., Feil, K. J., & Iacono, W. G. (2001). Saccadic disinhibition in acute and remitted schizophrenia patients and their first-degree biological relatives. *American Journal of Psychiatry*, *158*, 100–106.
- Friedman, L., Abel, L. A., Jesberger, J. A., Malki, A., Brar, R., & Meltzer, H. Y. (1992). A methodology for the assessment of smooth pursuit dysfunction in psychiatric patients and normal controls. *International Journal of Methods in Psychiatric Research*, *2*, 209–216.
- Hunter, J. E., & Schmidt, F. L. (1990). *Methods of meta-analysis: Correcting error and bias in research findings*. Newbury Park, CA: Sage.
- Iacono, W. (1988). Eye movement abnormalities in schizophrenic and affective disorders. In C. J. Johnston & F. J. Pirozzolo (Eds.), *Neuropsychology of eye movements* (pp. 115–145). Hillsdale, NJ: Erlbaum.
- Iacono, W. G., & Clementz, B. A. (1992). A strategy for elucidating genetic influences on complex psychopathological syndromes (with special reference to oculomotor functioning in schizophrenia). In L. J. Chapman, J. P. Chapman, & D. C. Fowles (Eds.), *Progress in experimental psychopathology research* (Vol. 16, pp. 11–65). New York: Springer.
- Iacono, W. G., & Lykken, D. T. (1981). Two-year retest stability of eye tracking performance and a comparison of electro-oculographic and infrared recording techniques: Evidence for EEG in the electro-oculogram. *Psychophysiology*, *18*, 49–55.
- Iacono, W. G., & Lykken, D. T. (1983). The assessment of smooth-tracking dysfunction. *Schizophrenia Bulletin*, *9*, 44–50.
- Jacobsen, L., Hommer, D., Hong, W., Castellanos, F., Frazier, J., Giedd, J., & Rapoport, J. (1996). Blink rate in childhood-onset schizophrenia: Comparison with normal and attention-deficit hyperactivity disorder controls. *Biological Psychiatry*, *40*, 1222–1229.
- Jacobsen, L., Hong, W., Hommer, D., Hamburger, S., Castellanos, F., Frazier, J., Giedd, J., Gordon, C., Karp, B., McKenna, K., & Rapoport, J.L. (1996). Smooth pursuit eye movements in childhood-onset schizophrenia: Comparison with attention-deficit hyperactivity disorder and normal controls. *Biological Psychiatry*, *40*, 1144–1154.
- Kumar, A., & Krol, G. (1992). Binocular infrared oculography. *Laryngoscope*, *102*, 367–378.
- Leigh, R. J., & Zee, D. S. (1999). *The neurology of eye movements*. (3rd ed.). New York: Oxford University Press.
- Litman, R. E., Hommer, D. W., Radant, A., Clem, T., & Pickar, D. (1994). Quantitative effects of atypical neuroleptics on smooth pursuit eye tracking in schizophrenia. *Schizophrenia Research*, *12*, 107–120.
- Moser, A., Kompf, D., Arolt, V., & Resch, T. (1990). Quantitative analysis of eye movements in schizophrenia. *Neuro-ophthalmology*, *10*, 73–80.
- Radant, A. D., & Hommer, D. W. (1992). A quantitative analysis of saccades and smooth pursuit tracking during visual pursuit tracking: A comparison of schizophrenics with normals and substance abusing controls. *Schizophrenia Research*, *6*, 225–235.
- Ross, D. E., Thaker, G. K., Buchanan, R. W., Kirkpatrick, B., Lahti, A. C., Medoff, D. R., Bartko, J. J., Goodman, J., & Tien, A. Y. (1997). Eye tracking disorder in schizophrenia is characterized by specific ocular motor defects and is associated with the deficit syndrome. *Schizophrenia Research*, *24*, 244.
- Ross, R. G., Olincy, A., & Radant, A. (1999). Amplitude criteria and anticipatory saccades during smooth pursuit eye movements in schizophrenia. *Psychophysiology*, *36*, 464–468.
- Schmid-Burgk, W., Becker, W., Diekmann, V., Jurgens, R., & Kornhuber, H. (1982). Disturbed smooth pursuit and saccadic eye movements in schizophrenia. *Archives of Psychiatry and Neurological Sciences*, *232*, 381–389.
- Sibony, C., & Evinger, P. A. (1998). Anatomy and physiology of normal and abnormal eyelid position and movement. In N. R. Miller & N. J. Newman (Eds.), *Walsh & Hoyt's clinical neuro-ophthalmology* (5th ed., Vol. 1, pp. 1509–1592). Baltimore, MD: Williams and Wilkins.
- Stern, J. A., Walrath, L. C., & Goldstein, R. (1984). The endogenous eye blink. *Psychophysiology*, *21*, 22–33.
- Tecce, J. J., Savignano-Bowman, J., & Kable, J. B. (1978). Effects of visual distraction on contingent negative variation and type A and B CNV shape. In D. A. Otto (Ed.), *Multidisciplinary perspectives in event-related brain potential research* (pp. 358–363). Washington DC: Environmental Protection Agency.
- Whicker, L., Abel, L. A., & Dell'Osso, L. F. (1985). Smooth pursuit eye movements in the parents of schizophrenics. *Neuro-ophthalmology*, *5*, 1–8.

(RECEIVED November 8, 1999; ACCEPTED February 8, 2001)