ELSEVIER

International Journal of Psychophysiology 19 (1995) 33–40

INTERNATIONAL JOURNAL OF PSYCHOPHYSIOLOGY

Changes in visual fixation and saccadic eye movements in Alzheimer's disease

Frederick W. Bylsma [a,*], D. Xeno Rasmusson [a], George W. Rebok [b], Penelope M. Keyl [c], Larry Tune [a], Jason Brandt [a]

[a] *Department of Psychiatry and Behavioral Sciences, The Johns Hopkins University School of Medicine, Meyer 218, 600 North Wolfe Street, Baltimore, MD 21287-7218, USA*

[b] *Department of Mental Hygiene, The Johns Hopkins University School of Public Health & Hygiene, Baltimore, Maryland, USA*

[c] *Department of Epidemiology, The Johns Hopkins University School of Public Health & Hygiene, Baltimore, Maryland, USA*

Received 15 March 1994; revised 3 September 1994; accepted 12 September 1994

Abstract

Visual fixation and saccadic eye movements were assessed in 31 mild to moderately demented patients with probable Alzheimer's disease (AD) and 31 age- and education-matched nondemented elderly control subjects. Seventeen AD and 17 matched control subjects were reassessed after a 9-month interval. On a fixation task, duration of fixation and number of intrusive saccades were not different between groups at baseline or follow-up. Both AD patients and control subjects showed more intrusive saccades at follow-up than at baseline. AD patients showed increased latency to initiation of saccades at baseline and on follow-up. Amplitude and velocity of saccades were not different between groups at any visit. Changes in measures of fixation, but no saccade measure, correlated with changes in MMSE scores over testing sessions. These data suggest that fixation is more sensitive than are saccades to the progression of AD.

Keywords: Fixation; Saccades; Alzheimer's disease; Aging; EOG; Longitudinal changes

1. Introduction

Oculomotor performance has not been extensively studied in Alzheimer's disease (AD). However, studies to date have been consistent in reporting poor performance in AD patients. Pursuit tracking impairments, in the form of low velocity gain and increased saccadic intrusions and 'catch-up' saccades, have been reported (Hutton et al., 1981, 1987; Kuskowski et al., 1989). Hutton (1985) tested 7 AD patients four times over a 1-year period and reported that the nature of impairment of sinusoidal pursuit tracking changed over a one-year interval. Initially, a high number of saccadic intrusions were noted in the tracking patterns of AD patients. Over testing sessions, the number of intrusive saccades decreased but their amplitude increased. A cross-correlation measure of eye-target position match showed a decrease over time, suggesting a progressive impairment of pursuit tracking in AD. At

* Corresponding author.

SSDI 0167-8760(94)00060-3

the first assessment, the number of saccadic intrusions and the cross-correlation measure correlated with severity of dementia, as indexed by Mini Mental State Examination (MMSE; Folstein et al., 1975) scores and a measure of functional abilities (Hutton, 1985). All patients showed more impaired performance over time when the cross-correlation measure was analyzed. However, it is unclear whether changes in pursuit performance correlate with the changes in cognitive abilities.

Fixation, the ability to keep the eye focussed on a target for a sustained period of time, has been reported to be abnormal in AD (Feldon and Langston, 1977; Fletcher and Sharpe, 1986; Jones et al., 1983). Patients' attempts to fixate a target are characterized by an inability to inhibit intrusive saccades. Typically, patients will look away from the fixation target momentarily and then move the eye back to the fixation target in a fashion similar to 'square wave jerk' intrusions in pursuit tracking (Hutton, 1985; Fletcher and Sharpe 1986). Jones et al. (1983) found abnormalities of fixation to be correlated with severity of dementia, but Fletcher and Sharpe (1986) reported no such relationship in their AD patients. Stability of fixation performance over repeated assessments has not been assessed in AD patients.

Saccade latency is significantly longer in AD patients than elderly control subjects (Hershey et al., 1982; Pirozzolo and Hansch, 1981). Fletcher and Sharpe (1986) found that, relative to age-matched control subjects, AD patients had increased saccade latency and reduced velocity if the target movements were unpredictable, and made more hypometric saccades and multi-step saccades than age-matched control subjects when target location was predictable. Pirozzolo and Hansch (1981) found saccade latency to be longest in their most demented patients. Fletcher and Sharpe (1986) found no such correlation with cognitive impairment. Other measures of saccade performance have not been shown to be related to dementia severity. No study has assessed saccade performance repeatedly over time in AD patients.

In the present study, visual fixation and saccadic eye movement performance were assessed in a large group of AD patients and age- and education-matched control subjects at baseline and again after 9 months. The relationships between oculomotor performance and dementia severity at baseline, and between changes in oculomotor performance and dementia severity over time are reported.

2. Methods

Subjects

Forty-two patients meeting ADRDA-NINCDS diagnostic criteria for probable AD (McKhann et al., 1984) and 81 healthy elderly control subjects were recruited to participate in a longitudinal study of automobile driving in Alzheimer's disease. The majority of AD patients were mildly to moderately demented at the first visit. Exclusion criteria for the patient and control subjects were current serious medical problems, a history of or current major psychosis, current untreated depression, past or current alcohol or substance abuse, and significant neurological impairment due to disease (e.g., Parkinson's disease) or trauma.

Of the 42 AD patients, 31 completed the eye movement testing. The other 11 patients were not tested either for technical reasons (data acquisition computer failure; $n = 7$) or because they were not cooperative during testing ($n = 4$). All control subjects had completed eye movement testing, and a sample of 31, matched to the AD patients for age (within 1 year) and education (within 2 years), served as the control group. Demographic data for these groups of subjects are presented in Table 1. As expected, MMSE scores for the AD patients were lower than those for the normal controls ($F(1,60) = 99.38$, $p < 0.001$). Also, the AD patients' visual acuity, after correction, was significantly worse than that of control subjects ($F(1,60) = 10.38$, $p < 0.002$). Seventeen of the AD patients returned for a follow-up visit after 9 months. The 17 control subjects who were matched for age and education to those patients were also reassessed after 9 months. Table 2 presents the demographic information for these subjects. As in the entire sample, these

Table 1
Demographics of AD and elderly control subjects in age-, and education-matched samples (mean (SD))

	AD Patients	Normal Elderly	p
n	31	31	
Age	71.8 (6.1)	71.4 (5.6)	0.813
MMSE score	20.1 (4.6)	28.6 (1.3)	0.001
Education, yrs.	13.2 (3.8)	14.2 (4.3)	0.289
Visual Acuity	39.8 (14.5)	29.8 (8.9)	0.002
Glasses (Yes/No)	16/15	20/11	0.609 [a]
Sex (Male/Female)	18/13	16/15	0.612 [a]

[a] Chi-square statistic.

AD patients had lower MMSE scores and worse corrected visual acuity than normal elderly control subjects.

Recording conditions and procedures

Eye movements were recorded via electrooculography (EOG) because many of the patients and control subjects required corrective lenses for accurate vision. It is recognized that EOG recordings are subject to muscle and EEG artifact (Iacono and Lykken, 1981; Lindsey et al., 1978; Ong and Harman, 1979), so conservative corrections were applied to the eye movement measures of interest. In scoring both saccade and fixation data, only deflections greater than 2° were counted as true eye movements. Although this cut-off may underestimate the number of small saccades made during the fixation task, it does instill confidence that the deflections counted reflect real eye movements.

Table 2
Demographics of age- and education-matched AD and elderly control subjects in the longitudinal component of the study (mean (SD))

	AD Patients	Normal Elderly	p
n	17	17	
Age	71.2 (6.3)	71.3 (6.4)	0.935
MMSE-Baseline	20.8 (3.5)	28.5 (1.3)	0.001
MMSE-Visit 2	18.3 (3.8)	28.9 (0.9)	0.001
Education, yrs.	12.5 (4.7)	13.5 (2.9)	0.464
Acuity-Baseline	41.1 (16.1)	30.0 (9.0)	0.017
Acuity-Visit 2	38.8 (19.6)	30.6 (12.2)	0.151
Glasses (Yes/No)	5/12	11/6	0.039 [a]
Sex (M/F)	8/9	12/5	0.169 [a]

[a] Chi square statistic.

Horizontal (HEOG) and vertical (VEOG) eye movements were recorded from Ag/AgCl 11-mm mini-electrodes (SensorMedics) placed at the outer canthi of each eye and above and below the right eye, respectively. Electrodes sites were cleaned with *OmniPrep* paste to ensure adequate impedance levels. If any evidence of drift was noted in the recordings, the electrodes were removed, the skin recleaned, and the electrodes reapplied. EOG data were recorded as dc potentials on Grass Instruments model 8A14 dc/ac amplifiers, filtered dc to 70 Hz (6 dB roll-off per octave), with a 60 Hz notch filter engaged. Analogue vertical and horizontal eye movement and target stimulus signals were digitized via analogue-to-digital (A/D) conversion at a sampling rate of 1000 points per second per channel (1 point per msec). Digitized data were stored on digital tape for off-line analysis.

After electrodes were applied, subjects were seated in front of a 19″ computer monitor at a distance of 26 inches (637 mm). To reduce head movement, subjects rested their head on a chin rest and restraint bars pressed against each side of the head. The stimulus was a 2×8 mm (0.2×0.7 degrees of visual angle) yellow rectangle on a dark gray background. The recording session included a calibration trial, a fixation trial, and a predictable saccades trial.

During the calibration trial, three stimuli, at the center of the screen and 10 degrees to the left and right of center, remained on the screen. The subject was told to fixate the center stimulus for about 1 sec, then to fixate the left stimulus, then the center stimulus, then the right stimulus, etc., for a minimum of 20 repetitions. A trigger pulse at the beginning of the calibration trial initiated A/D conversion and recording of eye movement data.

On the fixation task, the stimulus was presented at the center of the computer screen at eye level and remained there for 30 sec. Subjects were instructed to keep their eyes fixed on the stimulus for as long as possible without looking away. Subjects were asked to inhibit blinking during this time, but could do so if they needed to. Only the last 25 sec of the trial recording were used for data analysis.

The saccade task began with a stimulus presented at eye level in the center of the computer screen. To elicit saccades, the central stimulus disappeared and reappeared 1.5 degrees to the right and then left of center to elicit a 3 degree saccade. This was repeated such that seven saccades were elicited at each of four saccade amplitudes: 3, 7, 15, and 22 degrees. The stimulus remained on the screen at each location for 1.5 sec and moved predictably. Subjects were instructed that when the target stimulus moved, they were to move their eyes as quickly as possible to the new target location and fixate on the stimulus. They were asked to inhibit blinking as much as possible during the recording, and not to anticipate the stimulus' movement. The saccade task took 45 sec and data were recorded continuously throughout the trial.

Eye movement quantification

Computer software was developed in-house (FWB; Borland Turbo Pascal language) to score the eye movement data. First, the calibration data were scored to determine the digital equivalent of 1 degree of visual angle. A 1.4 sec sample of HEOG and VEOG data, beginning at the presentation of the trigger pulse was displayed on the screen. Saccades associated with blinks (e.g., large deflections of the VEOG trace which returned to baseline within ± 200 msec of the saccade), movement, or other artifact were not used. The beginning of the saccade (the point of inflection leading into the saccade) and the end of the saccade (the point of inflection when the saccade ended) were identified. The amplitude of the saccade in digital data points was determined by subtracting the digital EOG value at the beginning from that at the end of the saccade. A minimum of 15 saccades from the calibration trial were used to compute the average digital datapoint value equivalent to 1 degree of eye movement. The subject's individual calibration value was stored on disk for use by the saccade and fixation scoring routines.

To score the fixation data, HEOG and VEOG data recorded during that trial were presented on the computer screen in 1.4 sec samples. A 25-sec period of fixation, beginning 5 sec after the trial began, was scored. The number of intrusive saccades 2 degrees or larger, and not related to blinks were counted. In addition, the longest period of fixation, in sec, without a saccade was recorded.

Saccades were scored for latency of initiation of the saccade from stimulus onset, amplitude of the saccade, and maximal velocity of the saccade. Only saccades not associated with blinks, movement, or other artifact were scored. A 1.4 sec sample of HEOG and VEOG data, beginning at the time of target displacement was displayed on the computer screen. The saccade latency was the time elapsed from target displacement to the point of inflection leading into the saccade was scored as the latency of the saccade. The amplitude of the saccade, in degrees, was determined by obtaining the difference in the digital EOG values at the beginning and end of the saccade and dividing this value by the subject's individual calibration value. Maximal velocity of the saccade was determined for the period between the beginning and the end of the saccade by computing the velocity across a sliding 4 msec window.

In many instances, subjects made an initial saccade followed by one or more smaller saccades to effect the total eye movement in response to a single target displacement. For these situations, an adjusted amplitude score was computed. Specifically, the amplitudes of all saccades made in response to that stimulus were summed. However, only the first of those saccades was scored for latency, amplitude, and maximal velocity.

Statistical analyses

To assess baseline performance on the fixation task, analyses of variance (ANOVA) were performed on the number of intrusive saccades and the duration of the longest fixation with subject Group as the independent grouping factor. Baseline performance on the saccade task was assessed with a series of four ANOVAs for repeated measures. Subject Group (AD vs. Control) served as the independent grouping factor with Target movement amplitude (3 vs. 7 vs. 15 vs. 22 degrees) as the repeated factor. Amplitude, adjusted amplitude, latency, and maximal velocity were the dependent measures. To assess the rela-

tionship between severity of oculomotor performance deficit and the severity of dementia in AD patients, measures of fixation accuracy and saccade performance were correlated (Pearson product-moment correlations) with MMSE scores.

To assess changes in fixation and saccades over time, these data were analyzed with a repeated measures ANOVA, with Group as the grouping factor and Session (Baseline vs. Visit 2) as the repeated factor. Because no meaningful Target amplitude-related differences were noted at baseline, only the 7 and 15 degree saccades were analyzed. Latency, amplitude, and maximum velocity measures were assessed for each target amplitude separately. Correlations between Baseline MMSE scores, change in MMSE over sessions (baseline MMSE – Visit 2 MMSE) and change in fixation and saccade measures were computed to examine the relationship between change in dementia severity and change in oculomotor measures over time.

3. Results

Baseline performance

Representative EOG recordings of fixation and saccadic eye movements from an elderly control subject and an AD patient appear in Fig. 1. The groups did not differ on the fixation task. Patients and elderly control subjects had an equal number of intrusive saccades during fixation (AD: $M = 1.7$, $SD = 2.1$; Control: $M = 2.0$, $SD = 3.08$) and the duration of the longest period of fixation (AD: $M = 19.0$, $SD = 5.0$; Control: $M = 19.7$, $SD = 6.3$) was the same across groups. Intrusive saccades were infrequent, averaging about 2 in 25 sec of fixation. However, for the AD group, the number of intrusive saccades and the duration of fixation correlated with MMSE scores (Saccades: $r = -0.29$, $p < .05$; Duration: $r = 0.35$, $p < .03$), indicating that fixation is worse in more severely demented AD patients. Similar correlations computed for the control group were not significant, no doubt due to the restricted range of MMSE scores in this group.

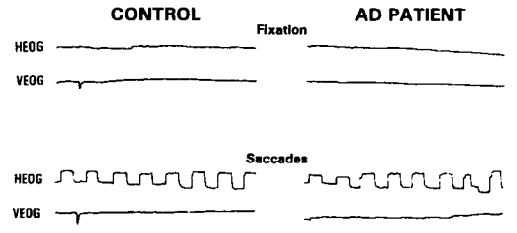

Fig. 1. Representative EOG recordings of fixation and saccadic eye movements from an elderly control subject and an AD patient. The vertical and horizontal bars represent 10 degrees and 1 sec, respectively.

On the saccade task, as target displacement increased, both groups showed the expected significant increases in saccade amplitude, adjusted amplitude, and maximum velocity. Saccade latency remained relatively constant across Target displacements (Table 3). Statistical analyses revealed no significant Group differences for the amplitude, adjusted amplitude, or maximum velocity of saccades. However, the main effect for Group was significant for the saccade latency measure, with AD patients having longer latencies than the control subjects ($F(1,60) = 4.66$, $p < .035$). No interactions involving Group were

Table 3
Saccade measures for each amplitude of target displacement by subject group

		3 Degrees		7 Degrees		15 Degrees		22 Degrees	
		NC	AD	NC	AD	NC	AD	NC	AD
Latency	M	191.7	229.1	174.7	223.2	194.2	226.5	192.8	239.9
	SD	69.3	100.8	71.2	102.9	76.5	106.3	81.4	95.2
Amplitude	M	2.5	2.9	5.6	5.4	10.8	9.8	17.6	15.0
	SD	0.7	1.1	1.6	2.4	3.1	4.2	15.6	6.8
Adjusted	M	2.8	3.1	6.5	6.3	13.4	11.7	19.9	18.1
Amplitude	SD	0.7	1.0	1.3	2.3	2.9	3.4	4.7	6.3
Maximum	M	191.9	201.5	271.3	267.7	363.8	344.8	417.6	412.9
Velocity	SD	81.4	174.6	143.8	181.2	130.8	181.2	149.3	194.7

significant. For the AD patients, saccade latency was inversely correlated with MMSE scores (3 degree: $r = -0.38$, $p < .02$; 7 degree: $r = -0.19$, ns; 15 degree: $r = -0.27$, $p < .07$; 22 degree: $r = -0.41$, $p < 0.01$) indicating that more demented patients have longer saccade latencies. As with the fixation measures, control group correlations between MMSE and saccade latency were not significant.

Changes in fixation and saccades over time

On the fixation task, the main effect for Group for both the number of intrusive saccades or the duration of the longest fixation was nonsignificant. However, the main effect for Session was, indicating an increase in the number of saccades during fixation from Baseline to Visit 2 (AD: Baseline – $M = 1.1$, SD = 1.6, 9-Month – $M = 3.9$, SD = 4.8; Control: Baseline – $M = 1.8$, SD = 2.8, 9-Month – $M = 3.3$, SD = 3.7; $F(1,32) = 7.39$, $p < 0.02$). The duration of the longest fixation did not change over the 9-month interval. The Group by Session interactions for both measures were not significant. For the AD patients, increased numbers of intrusive saccades correlated with baseline MMSE ($r = -0.39$, $p = 0.06$), and with the decrease in MMSE score over the 9-month interval ($r = -0.42$, $p < 0.05$). These correlations for the control group were not significant. Duration of fixation was not correlated with MMSE score change for either group.

Fixation performance over a longer time interval was examined in the 8 AD patients and 14 controls who had three eye movement evaluations: baseline, and 9 and 18 months after their baseline visit. These data, presented graphically in Fig. 2, were not analyzed statistically because of the small and unequal sample sizes. However, the AD patients show a pattern of increasing intrusive saccades over the three testing sessions while the control subjects do not. Duration of fixation shows less of an effect.

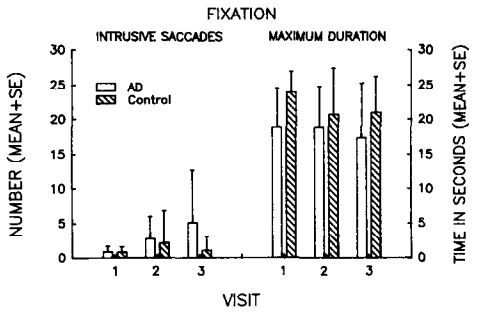

Fig. 2. Fixation measures at Baseline, after 9, and after 18 months in 8 AD and 14 elderly control subjects.

On saccade measures (see Table 4), Group differences were noted for saccade latency ($F(1,32) = 4.43$, $p < 0.05$) and maximum velocity ($F(1,32) = 4.55$, $p < 0.05$) on visit 2. There was no significant main effect of Session or significant Group by Session interactions for any of the saccade measures. There were no significant correlations between change across sessions in saccade measures and dementia severity, as indexed by MMSE scores.

Table 4
Saccade measures for 7 and 15 degree target displacements at baseline and after 9 months

		7 Deg./Visit 1		7 Deg./Visit 2		15 Deg./Visit 1		15 Deg./Visit 2	
		NC	AD	NC	AD	NC	AD	NC	AD
Latency	M	193.1	236.3	190.9	174.9	187.8	226.5	164.5	239.9
	SD	97.4	119.5	178.2	65.1	89.6	117.6	61.1	65.9
Amplitude	M	5.2	5.5	5.3	4.9	10.7	10.6	10.6	10.6
	SD	1.8	2.4	1.3	1.8	3.6	4.8	2.1	8.1
Adjusted	M	6.3	6.2	6.3	5.9	13.8	12.0	13.0	11.9
Amplitude	SD	1.6	2.4	1.0	1.5	3.4	2.1	2.1	3.4
Maximum	M	224.7	261.8	252.8	222.3	336.4	344.6	367.4	298.6
Velocity	SD	95.0	183.2	94.4	91.8	125.8	192.9	92.8	95.3

4. Discussion

Performance on visual fixation and saccadic eye movement tasks was compared in a group of mildly to moderately demented AD patients and age- and education-matched control subjects at baseline and after a 9-month interval. The groups performed equally well on the fixation task at baseline, and both groups showed an increase in intrusive saccades when retested after 9 months. Examination of fixation performance in small groups of AD and control subjects 18 months after the baseline visit showed AD patients' intrusive saccades continued to increase while, for the control subjects, these intrusions returned to baseline levels. For the AD patients the increase in intrusive saccades was related to increased cognitive impairment, as indexed by lower MMSE scores at follow-up. On the saccade task, the groups differed at baseline in latency to initiate a saccade after target displacement. The extent of this difference was related to MMSE scores at baseline. However, saccade latencies showed no change over time and were not associated with increasing dementia severity. No other measure of saccade performance differentiated the AD patients from the control subjects.

Hutton (1985) showed AD patients' pursuit eye movements are impaired, and that they become increasingly impaired over time. Both Jones et al. (1983) and Fletcher and Sharpe (1980) found impaired fixation in AD patients. Jones et al. (1983) reported that in their small group, the most demented patients showed the greatest impairment of fixation, but Fletcher and Sharpe (1986) reported no such relationship in their patients. Intrusive saccades are characteristic of both fixation and pursuit eye movements in AD patients. The present study found AD and Control subjects to make equal numbers of intrusive saccades at baseline. A progressive increase in the number of intrusive saccades over 9- and 18-month intervals was noted only for AD patients, and this increase correlated with increased dementia severity, as indexed by MMSE scores. This latter finding contrasts with those of Hutton (1985) who reported that, during pursuit eye movements, saccadic intrusions tended to decrease in number but increase in amplitude over a 1-year period. These data support the distinction between pursuit eye movements and fixation (Leubke and Robinson, 1988). Taken together, findings of the present study and those of previous studies suggest that the progressive impairment of ocular fixation may serve as a psychophysiological marker of cognitive decline in AD patients.

Saccadic eye movements made in response to a predictable target motion by AD patients are of increased latency. Amplitude and velocity were not impaired, confirming previous studies of saccades in AD patients where a predictable target was used (Fletcher and Sharpe, 1986; Jones et al., 1983; Hershey et al., 1982). There was no significant change in latency over time; patients' and control subjects' saccade latency remained stable over the 9-month follow-up interval. For the AD patients, baseline latency was related to MMSE scores, but there was no correlation of saccade latency change and MMSE score change over the follow-up period. Cortical control of saccades comes primarily from the frontal eye fields and supplementary motor cortex. The frontal lobes are typically spared early in the course of AD, and that may help explain the lack of correlation between change in saccade latency and increased severity of dementia over the follow-up period of this study. However, it would be predicted that greater saccade impairment would become evident when neuropathological changes impinge upon the frontal cortex.

Impairment of fixation and saccadic eye movements in AD patients could negatively impact performance of activities of daily living (Hutton, 1985). Impaired oculomotor control may hamper performance in situations requiring rapid processing of visual information, such as when driving an automobile. Driving safely requires rapid visual search of the environment for potential dangers, and also sustained focusing of both vision and attention on important stimuli such as traffic lights, intersection/direction signs, and other drivers' signal and brake lights. Recent studies have implicated poor visual information processing as an important contributor to unsafe driving behaviors in elderly persons (Ball and

Owsley, 1991; Owsley et al., 1991; Keyl et al., 1994; Rebok et al., 1994). The results of the present study suggest that at least a portion of the variance in driving performance attributable to poor visual information processing may be due to impaired eye movement.

Acknowledgements

This research was supported by NIA grants No. AG08327-03 and No. AG00149. The authors express their appreciation to Alice Rodman for subject recruitment and Carlos Rios who assisted with data acquisition and analysis.

References

Ball, K. and Owsley, C. (1991) Identifying correlates of accident involvement for the older driver. Hum. Fact, 33: 583–595.

Feldon, S.E. and Langston, J.W. (1977) Square-wave jerks: a disorder of microsaccades? Neurology, 27: 278–281.

Fletcher, W.A. and Sharpe, J.A. (1986) Saccadic eye movement dysfunction in Alzheimer's disease. Ann. Neurol., 20: 464–471.

Folstein, M.F., Folstein, S.E. and McHugh, P.R. (1975) Mini-Mental State: a practical method for grading cognitive state of patients for the clinician. J. Psychiat. Res., 12: 189–98.

Hershey, L.A., Whicker, L., Abel, L.A., Dell'Osso, L.F., Traccis, S. and Grossniklaus, D. (1982) Saccadic latency measurements in dementia. Arch. Neurol., 40, 592–593.

Hutton, J.T. (1985) Eye movements and Alzheimer's disease: significance and relationship to visuospatial confusion. In: Hutton, J.T. and Kenny, A.D. (Eds.), Senile Dementia of the Alzheimer Type, Alan R. Liss, New York, NY.

Hutton, J.T., Dippel, R.L. and Sung, J.H. (1987) Eye tracking in Pick disease as contrasted to Alzheimer disease. Neuro-ophthalmology, 7, 159–164.

Hutton, J.T., Shapiro, I., Loewenson, R.B., Christian, B.L., and Nagel, J.A. (1981) Abnormal eye movements in dementia and aging. Trans. Am. Neurol. Assoc., 106, 1–4.

Iacono, W.G. and Lykken, D.T. (1979) Comments on "Smooth-pursuit eye movements: A comparison of two measurement techniques". J. Abnorm. Psychol., 88, 678–680.

Iacono, W.G. and Lykken, D.T. (1981) Two-year retest reliability of eye tracking performance and a comparison of electro-oculographic and infra-red recording techniques: evidence of EEG in the electro-oculogram. Psychophysiology, 18, 49–55.

Jones, A., Friedland, R.P., Koss, B., Stark, L. and Thompkins-Ober, B.A. (1983) Saccadic intrusions in Alzheimer-type dementia. J. Neurol., 229, 189–194.

Keyl, P.M., Rebok, G.W., Bylsma, F.W., Tune, L., Brandt, J., Teret, S., Chase, G.A. and Sterns, H.L. (1994) Cognitive function, driving simulator performance, and crash history in Alzheimer's disease patients and elderly controls. Psychol. Aging, submitted.

Kuskowski, M.A., Malone, S.M., Mortimer, J.A. and Dysken, M.W. (1989) Smooth pursuit eye movement in dementia of the Alzheimer's type. Alzheimer Dis. Assoc. Dis., 3, 157–171.

Leubke, A.E. and Robinson, D.A. (1988). Transition dynamics between pursuit and fixation suggest different mechanisms. Vision Res., 28, 941–946.

Lindsey, D.T., Holzman, P.S., Haberman, S. and Yasillo, N.J. (1987) Smooth pursuit eye movements: a comparison of two measurement techniques for studying schizophrenia. J. Abnorm. Psychol., 87, 491–496.

McKhann, G., Drachman, D., Folstein, M., Katzman, R., Price, D., and Stadlan, E.M. (1984) Clinical diagnosis of Alzheimer's disease: Report of the NINCDS-ADRDA work group. Neurology, 34, 939–944.

Ong, J. and Harman, G.A. (1979). Eye movements simultaneously recorded by electrooculographic and photoelectric methods. Percept. Motil. Skills, 48, 619–624.

Owsley, C., Ball, K., Sloane, M.E., Roenker, D.L. and Bruni, J.R. (1991) Visual/cognitive correlates of vehicle accidents in older drivers. Psychol. Aging, 3, 403–415.

Pirozzolo, F.J. and Hansch, E.C. (1981). Oculomotor reaction time in dementia reflects degree of cerebral dysfunction. Science, 214, 349–351.

Rebok, G.W., Keyl, P.M., Bylsma, F.W., Blaustein, M.J. and Tune, L. (1994) The effects of Alzheimer's disease on driving-related abilities. Alzheimer Dis. Assoc. Disord., in press.