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Effects of Age and Hemianopic Visual Field Loss on Driving

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ABSTRACT

Purpose. **With the use of an interactive driving simulator, we examined the driving performance of older patients with either homonymous or quadrantic hemianopsia with primarily occipital lobe damage resulting from cerebrovascular accidents (CVA's).** ***Methods.*** **We compared the performance of these patients with that of a normally sighted, age-similar control group and that of a normally sighted younger group.** ***Results.*** **The driving performance of the patients was either worse than, or similar to, that of the older control group; all of the older individuals (both patients and normally sighted subjects) had worse performance than the younger group.** ***Conclusions.*** **Age-related effects combined with the effects of visual field losses in older patients with cerebrovascular accidents had a negative impact on driving skills.**

Key Words: hemianopsia, stroke, aging, driving ability

A clear relation has not been demonstrated between cerebral lesions and sensorimotor behavior in general, and driving skills in particular. Attempts to quantify deficits in driving-related abilities have outlined the importance of the hemispheric location of the lesion (right *versus* left) and the nature of the task (sensory *versus* cognitive level). For example, patients with right-hemisphere infarcts are more likely to exhibit slowed reaction times and hemispatial neglect, whereas patients with left-hemisphere damage more often exhibit verbal processing deficits.[1] When factors that are directly related to driving in stroke and trauma patients were examined, cognitive/motor deficits were found to have a profound effect.[2,3] A majority of these studies assessed driving-related skills in patients with damage involving the association cortex who exhibited both cognitive and motor dysfunction. The effects of primary sensory defects in stroke patients on their driving performance have not been directly examined.

We studied a sample of patients who had cerebrovascular accidents (CVAs) with damage primarily localized to the occipital cortex. We quantified their performance on a driving simulator.[4,5] This simulator directly measures the interaction of sensory input with cognitive/motor function in driving scenarios. Previous studies have demonstrated that this simulator provides a sensitive assay of driving performance in patients with direct sensory-based losses of visual input.[4,5]

A large body of literature indicates that sensory, cognitive and motor deficits are associated with aging (see Refs. 6–8 for reviews). In addition, numerous studies have examined the effects of aging specifically on driving performance (see Refs. 9–11). Because of the advanced ages of our patients with CVA, we compared their data with those obtained from a group of age-similar, normally sighted individuals. This allowed us to separate the sensory and cognitive losses resulting from aging alone from those resulting from aging combined with sensory losses caused by stroke.

METHODS

Patients

Six patients (2 women and 4 men) ranging in age from 53 to 80 years (mean, 71 years) participated in the study. These patients had hemianopic visual field deficits resulting from CVAs, affecting primarily the occipital cortex. Every patient underwent computerized tomography and/or magnetic resonance imaging to ascertain the nature and the location of the lesion. Table 1 gives the clinical characteristics of the patients.

Four of the patients had right hemianopic field

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TABLE 1. Patient characteristics.

Patient No./Age (yr)/Sex	Snellen Visual Acuity[a]		Site of Infarct	Visual Field	Neglect
	OS	OD			
1/63/M	6/9	6/6	Right postchiasmal visual pathways affecting both parietal and occipital lobe areas	Left hemianopsia with macular sparing	Yes
2/53/F	6/6	6/6	Right occipital pole; significant portion of anterior and superior striate cortex spared	Left superior quadrantic hemianopsia	No
3/67/M	6/6	6/7.5	Left postchiasmal visual pathway; lesion primarily to visual cortex, likely in optic radiations; occipital pole and portion of inferior bank of calcarine cortex spared	Right inferior quadrantic hemianopsia	No
4/67/M	6/4.5	6/6	Left calcarine cortex extending to occipital pole	Right hemianopsia with macular splitting	No
5/79/F	6/7.5	6/7.5	Left occipital and parietal lobe areas	Right hemianopsia	Yes
6/80/M	6/6	6/7.5	Left occipital and parietal lobe areas	Right hemianopsia	Yes

[a] OS, left eye; OD, right eye.

deficits; 2 of these patients neglected the right visual field. The other 2 patients had left hemianopic field defects, 1 of these patients neglected the left field. Neglect or spatial inattention was measured with the Line Bisection test[12] and a signature-writing task (used to determine whether the patient respects the midline of the visual field by centering the signature). All patients exhibited a best-corrected Snellen visual acuity of 6/7.5 (20/25) or better in at least one eye.

Superimposed on a view from the video display of the driving simulator (Figure 1A) are the binocular visual fields for representative left (Figure 1B) and right (Figure 1C) hemianopic patients, assuming the eyes and head are facing the simulator screen in a fronto-parallel position. The binocular field maps were produced by merging the monocular fields (by means of a Goldmann perimeter, V-4-e target) of each patient by the method described by Arditi.[13] All patients were tested within 2 months after their strokes. The patients had driven regularly before their strokes (at least 1000 miles per year according to self-report) and held valid unrestricted driver's licenses.

Older Control Subjects

Seven subjects (3 women and 4 men) with normal visual acuity (ranging from 6/4.5 to 6/6) and no eye disease or visual field loss were included as normal control subjects. They ranged in age from 62 to 83 years (mean, 70 years). All held unrestricted driver's licenses at the time of testing and drove regularly (at least 1000 miles per year according to self-report).

Younger Control Subjects

The findings of the hemianopic patients and the older control subjects were compared with the data on the driving performance of 31 younger control subjects (16 women and 15 men), from a previous study,[4] who had normal visual acuity and a normal-appearing fundus by ophthalmologic examination. The younger control subjects ranged in age from 21 to 64 years (mean, 39 years). All held valid unrestricted driver's licenses and drove at least 1000 miles per year.

Driving Assessment System

All subjects underwent testing on an interactive driving simulator that has been previously described in detail.[4,5] The simulator consisted of a seat, a steering wheel, gas and brake pedals, and an automatic transmission. The visual display system was composed of three 62.5-cm color monitors, synchronized to display the appropriate view of a computer-generated environment. The visual display provided 160^0 of horizontal viewing field and 35^0 of vertical viewing field to the subject seated 57.5 cm from the center screen. The mean luminance of the display was approximately 103 cd/m,^{2} as measured with a Spectra Spotmeter (Kollmorgen, Newburgh, NY). Testing was performed with the room lights off. Subjects were instructed to operate the simulator as they would normally drive their own car and to obey all traffic signs and signals along the roadway. After a 15-min training session on a practice course, data were collected for subjects' responses during a 5-min session of driving the test course.

Simulator Performance Indexes

The simulator indexes analyzed included the following:[1] number of lane boundary crossings (defined as any 1 of the 4 tires crossing over any of the lane's boundaries);[2] lane position;[3] steering angle (angular orientation of the steering wheel);[4] vehicle

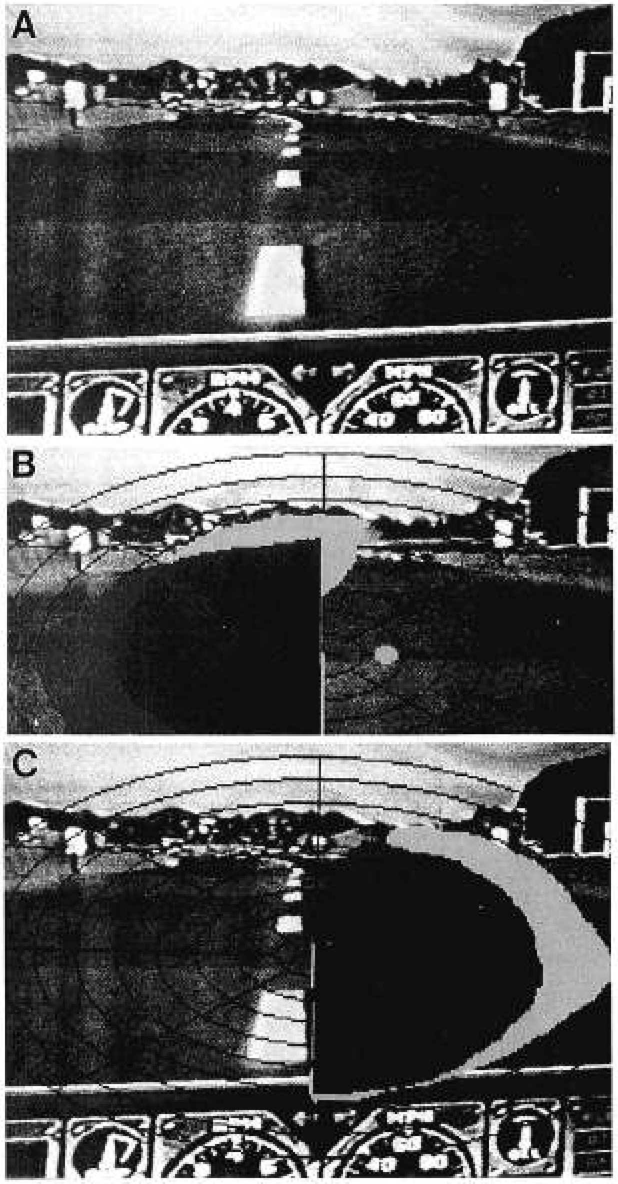

Figure 1. **(A)** A representative view of the center screen of the driving simulator. **(B)** The binocular visual field of a patient with a left homonymous hemianopic field defect superimposed on the visual scene shown in A. **(C)** The binocular visual field of a patient with a right homonymous hemianopic field defect superimposed on the visual scene shown in A.

angle to the road; (5 and 6) average slowing and average stopping to traffic signals (defined as the elapsed time between the presentation of 3 individual traffic signal events and the initiation of a brake pedal response and the elapsed time to a complete stop);[7] mean speed (in miles per hour);[8] gas pedal pressure (in arbitrary units; calculated as the mean in gas pedal pressure during the session);[9] braking pedal pressure (in arbitrary units; calculated as the mean in brake pedal pressure during the session); and[10] simulator accidents.

Subjects were able to monitor their travel speed in 4 ways:[1] by a speedometer located on the central monitor;[2] by flow fields created by passing landscape and traffic and by alternating dark- and light-gray stripes extending horizontally across the roadway;[3] by turning resistance on the steering wheel; and[4] by alterations in engine sound with changing speeds. Lane boundaries were defined by a yellow median stripe and by contrast changes at the edge of the roadway. These defining features extended peripherally into the side monitors.

All collisions with road obstacles or other vehicles were recorded on the simulator as accidents. There were 6 staged challenges on the simulator course that required visuocognitive/motor skills to avoid an accident, including three intersections with cross traffic, a car passing on the left, a cow approaching from the right and crossing the road, and a car merging onto the simulator roadway from an on-ramp. Each of these events was programmed to begin when the car reached specific points along the test course.

Eye and Head Movements

A camera (Hitachi model AP-130U, Hitachi Denshi, Ltd., Woodbury, NY), mounted above the simulator display captured the image of the subject as he or she drove, and the image was stored on tape via a video cassette recorder (U-Matic model NV-9200, Panasonic Corp., Secaucus, NJ). A time code was placed on the videotape via a computer (IBM/AT) interfaced with the simulator. The videotaped session was replayed and an image was frozen on the screen once every 4 s. The pixel location of the center of the pupil of each eye, the location of the center of a cross on a head marker, and the time code were recorded. The variability of the eye and head movement in the sequence of images was the index of movement.

Real-World Accident Reports

We analyzed information obtained from self-report about past accidents within a 5-year period. We found in our previous studies[4,5] that self-reported accidents were correlated with state records of accidents and that we could obtain information about more accidents through self-report, especially with subjects who have compromised vision.

RESULTS

Lane Boundary Crossings

Figure 2A shows the number of lane boundary crossings for each of the older groups and the mean and standard deviation (SD) for the younger, normally sighted group. A chi-square analysis showed significantly more lane boundary crossings for the hemianopic group than for the older group (chi-square[1] = 33.9, $p < 0.01$). There were no consistent differences between the patients with right and left visual field loss, nor were there differences between the patients with and without visual field neglect. In addition, older control subjects showed numbers of lane boundary crossings similar to those for the younger control group.

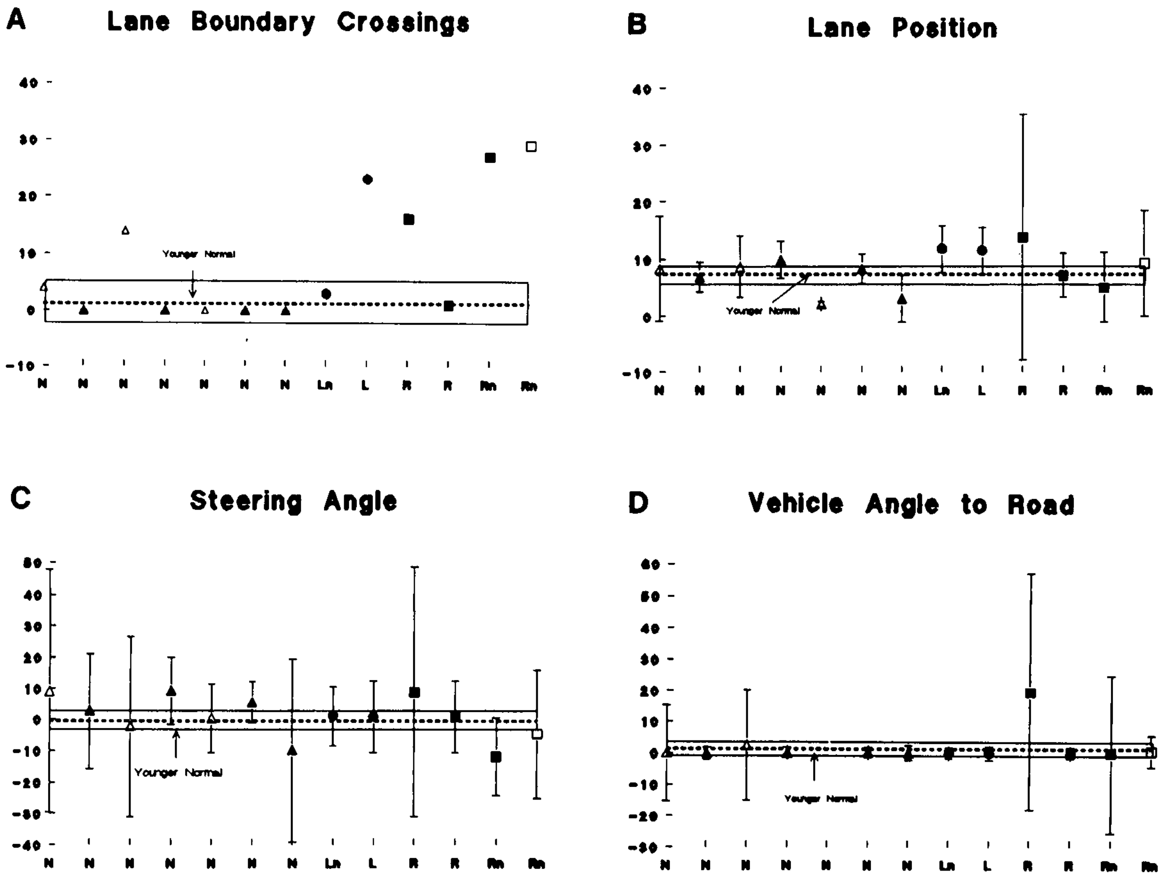

Figure 2. Individual performance on driving indexes for the patients and the older control subjects. Data from each older control subject are labeled *N* along the abscissa. The ages of the older control subjects are from left to right: 83, 80, 67, 64, 62, 75, and 64 years. Data from each hemianopic patient are labeled either *L* (left visual field defect) or *R* (right visual field defect). Data for those patients with field neglect are denoted with either *Ln* or *Rn*. Data for patients 1 through 6 (Table 1) are plotted in order from left to right along the abscissa. Open symbols denote those subjects who reported 1 or more real-world accidents within the previous 5 years. Each older subject's data are plotted as means ± 1 SD (when appropriate). The mean (broken line) ±1 SD (box) for the younger control group is shown on each figure. **A**-Lane Boundary Crosssings, **B**-Lane Position, **C**-Steering Angle, **D**-Vehicle Angle to Road.

Lane Position

Figure 2B shows the absolute lane position and the SD for this index for the older groups and the mean and SD for the younger group. In this plot, 0 represents the center line and the driver's lane is equivalent to 6.1 meters wide. Absolute lane position was unrelated to visual field status, and there were no consistent differences in absolute lane position between the older normally sighted and younger control subjects. However, variability of lane position was significantly greater in the patient group (t^{11} = - 2.20, $p < 0.05$).

Steering Angle

Figure 2C illustrates the steering angle, in clockwise positive degrees and counterclockwise negative degrees, for the older groups and the younger group. In this plot, 0 degrees represents the upright position. There were no statistically significant differences between the steering angles used by the patients and older normally sighted subjects (t^{11} = 0.74, not significant). Both the patients and the older normal subjects exhibited greater deviation in steering angle than did the younger normal subjects.

Vehicle Angle to the Road

Figure 2D plots the vehicle angle to the road data for each subject. In this plot, positive degrees represent deviations to the right and negative degrees indicate deviations to the left. There were no statistically significant differences in vehicle angle between the patients and the older normally sighted subjects (t^{11} = -1.10, not significant). Likewise, there were no differences between the older and younger normally sighted groups.

Average Slowing

Figure 3A illustrates the average slowing times for all groups. Although there was a large variability among individuals in slowing times observed for both the older normally sighted and the patient groups, there were no significant differences in the mean slowing times between these groups (t^{11} = 0.18, not significant). Four of the 7 older normally sighted subjects and 3 of the 6 patients had longer

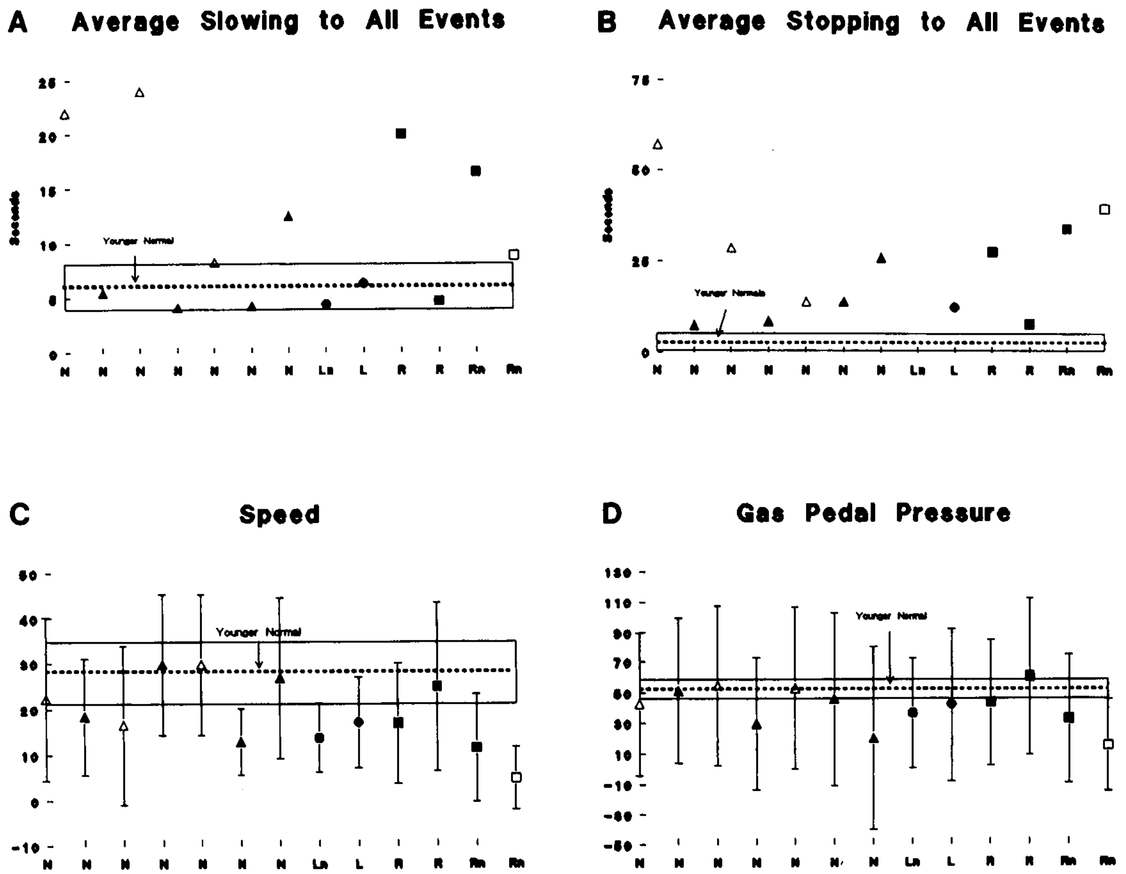

Figure 3. Data plotted as in Figure 2 for **A**-Average Slowing to All Events, **B**-Average Stopping to All Events, **C**-Speed, **D**-Gas Pedal Pressure.

average slowing times than did the younger normally sighted group. Interestingly, 2 of the 4 older subjects who had had real-world accidents had the longest slowing times of any subjects.

Average Stopping

Figure 3B illustrates the average stopping times for all groups. There was no difference between the mean stopping times for the normally sighted older subjects and the patients (t^{11} = 0.27, not significant). Both groups, however, had prolonged stopping times when compared with the younger normal subjects. Again, those subjects who had had real-world accidents generally had longer stopping times. The patient with left-field neglect did not stop to any of the traffic signals and, therefore, had no data point plotted.

Speed

Figure 3C plots the mean speeds (in miles per hour) for all groups. There were no differences between the mean speeds for the normally sighted older subjects and the patients (t^{11} = 0.61, not significant). Both groups, however, had generally slower average speeds than those of the younger normally sighted subjects.

Gas Pedal Pressure

Figure 3D shows the mean gas pedal pressure (in arbitrary units) over the course for each of the older groups and the mean and SD for the younger normally sighted group. There were no differences between the mean gas pedal pressures for normal subjects and patients (t^{11} = 0.15, not significant). Both groups, however, had generally lower average pedal pressure and greater variability in pedal pressure when compared with the younger normal subjects.

Brake Pedal Pressure

Figure 4A shows the mean brake pedal pressure (in arbitrary units) over the course for each of the older groups and the mean and SD for the younger normally sighted group. There were no differences between the mean brake pedal pressures for the older normally sighted subjects and the patients (t^{11} = 0.12, p = n.s.). Likewise, there were no differences between these groups and the younger normally sighted subjects in mean braking pressure. There was greater variability in brake pressure for both older groups when compared with the younger normally sighted subjects.

Simulator Accidents

Figure 4B gives the number of simulator accidents for the older groups; none of the younger subjects had an accident. Only 2 subjects (in the older normally sighted group) had simulator accidents; interestingly, these were 2 of the 4 older subjects who had reported real-world accidents.

Eye and Head Movements

Data for eye and head movements were plotted separately for the patients with and without field neglect (Figure 5). Those patients without neglect had eye movements similar to those of the older normal subjects, but these patients without neglect had greater head movement. Those patients with neglect had less eye and head movement than did the older normally sighted group.

DISCUSSION

Differences in driving performance indexes were found between the patients with primary sensory losses and the older controls. Lane boundary crossings and variability in lane position were significantly compromised in our older patients. In a previous study examining the driving performance of younger patients with retinitis pigmentosa, these same indexes were significantly related to peripheral visual field loss.[4] Variability in lane position was also predictive of real-world accidents in a logistic regression model when combined with extent of peripheral visual field loss in the same study.[4] It is not surprising, however, that patients with visual field losses show deficits on an index designed to assess visuo-spatial positioning skills.

In addition, the patients with CVAs and who did not have neglect showed greater head movements in the simulator than did their older control group. By using greater head movements, these patients may be able to expand their perceptual/visual field space in order to compensate for visual field losses when they are driving.

However, there were individual patients who demonstrated marked deficits in performance. For example, Patient 1, who had left-field neglect, failed to stop at any of the traffic signals along the course. This behavior could potentially represent a danger on the road if it were manifested under real-world circumstances. Patient 6, with right-field neglect, had outlier performance on a number of indexes, including the second-slowest average stopping time of any patient or subject, and the most lane boundary crossings, the lowest gas pedal pressure, and the slowest average speed of any patient or subject. Interestingly, this patient also reported having 1 real world accident within the 5 years prior to testing and was also the oldest patient in the study. Therefore, whereas most of the CVA patients were able to compensate and perform at levels nearly equivalent to the level of the normally sighted older group, other patients clearly demonstrated worse performance.

In our sample of patients, there was no relation between performance on driving indexes and the hemispheric location of the infarct. This finding is most likely due to the fact that the site of the lesions in our group of patients was primarily restricted to the occipital lobes where functionally the two hemispheres are fairly equivalent.

Older subjects (patients and normally sighted), in general, performed more poorly than younger subjects on driving simulator indexes. This is consistent with the findings of previous studies, which have revealed significant deficits in driving-related abilities in older normally sighted individuals.[11,14] Older subjects had a greater deviation in steering angle, had greater variability of gas pedal and brake pedal pressure, maintained slower average speeds, and had prolonged slowing and stopping times. Brake pedal pressure and reaction times were correlated with real-world accidents in both normally sighted individuals and patients with diseases localized to the retina.[4,5] Our older subjects also had more simulator accidents than did the younger subjects. A previous study found increased difficulties reported by older persons when responding to unexpected vehicles, in controlling vehicle speed, and in reading highway signs.[15] These self-reported problems are consistent with the deficits quantified when using our simulator.

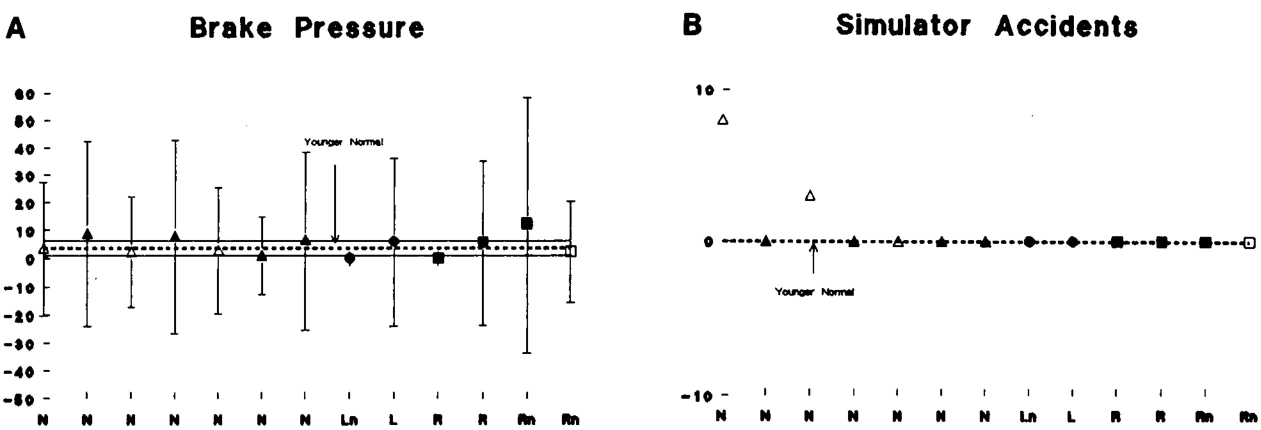

Figure 4. Data plotted as in Figure 2 for **A**-Brake Pressure, **B**-Simulator Accidents.

In summary, we found that older patients with primarily sensory-cortex localized infarcts, but with intact cognitive/motor function, perform worse than, or similar to, an age-similar control group on an interactive simulator. However, all older subjects perform more poorly than younger subjects in this simulated driving environment. These findings indicate that the sensory and cognitive losses associated with aging have a significant influence on driving-related skills. These age-related losses when compounded by CVA-associated impairments may further increase the on-road risk to these older hemianopic patients while driving.

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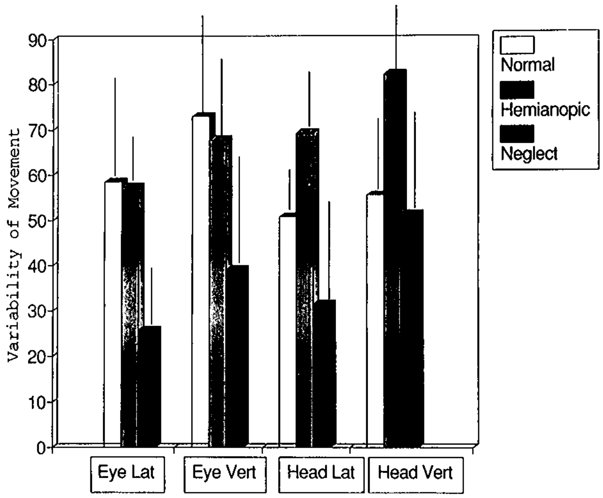

Figure 5. The mean variability (+1 SD) of lateral and vertical eye and head movements for each of the older groups.

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