Eye Movements in Parkinson's Disease: Before and After Pallidotomy

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Purpose. To evaluate the effects of unilateral, stereotactic, posteroventral pallidotomy on saccadic eye movements in patients with Parkinson disease (PD).

Methods. Eye movements of 31 patients with moderate to advanced PD were recorded with an infrared system 1 month before and 3 months after pallidotomy. Two kinds of saccade tasks were used: saccade tasks for eliciting visually guided saccades and saccade tasks for eliciting internally mediated saccades (memory-guided, predictive, and anti-saccades). Latency, accuracy, peak velocity, and other parameters of saccades were evaluated.

Results. Internally mediated saccades were more impaired in patients with advanced PD compared with those with moderate PD. Pallidotomy did not affect visually guided saccades. After pallidotomy, the peak saccadic velocity of internally mediated saccades decreased.

Conclusions. Hence, although pallidotomy has led to improvements in other motor functions, none were observed in saccadic responses. Rather, several modest decrements, below the level of clinical significance and all in internally mediated saccades, were observed. (*Invest Ophthalmol Vis Sci.* 2000;41:2177–2183)

Parkinson disease (PD) is associated with degeneration of the dopaminergic neurons in the substantia nigra, pars compacta (SN), and in regions surrounding the SN. PD patients demonstrate deficits in initiation and performance of internally mediated (anti-, memory-guided, and predictive) saccades.[1–8] These tasks have in common the fact that responses are triggered either consciously by the subject (memory-guided and anti-saccade) or in unconscious anticipation of repetitive target motion (predictive) rather than reflexively in response to a suddenly appearing visual stimulus. In predictive tasks,[1] PD patients were less able to anticipate target steps, and saccades were markedly hypometric. Similar deficits were described in memory-guided tasks.[2,3,5] In contrast, reflexive visually guided saccades made to randomly appearing visual targets were almost normal. Several authors[2,3,7–10] found normal mean latency, velocity, and accuracy of primary saccades in the visually guided saccade paradigms in most PD patients. In the anti-saccade task,[3,7,8] the performance of mildly to moderately affected PD patients was not impaired. Patients with advanced PD[6,8] demonstrated increased mean latencies and error rates in the anti-saccade task. In advanced PD, damage in other brain structures, such as the frontal lobe,[11] might produce these deficits in saccadic performance.

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Several studies[12–14] demonstrated that pallidotomy improved many aspects of motor performance, such as tremor, rigidity, and drug-induced dyskinesias. After pallidotomy, patients reported improvements in their condition as measured on a self-rating scale. A recent study[15] showed that stimulation by electrodes implanted in the ventral pallidum improved memory-guided and anti-saccades in PD patients. A recent positron emission tomography (PET) study[16] has found activity in the globus pallidus during a self-paced saccade task. In the present study, we measured the effect of stereotactic, posteroventral pallidotomy on reflexive, visually guided, and internally mediated saccades in PD patients. A preliminary study of the effects of pallidotomy on motor disability for some of these subjects has been reported.[17]

Methods

We studied 31 patients with idiopathic PD (21 men and 10 women; mean age ± SD, 63.2 ± 8.1 years; range, 45–78 years) 1 month before and 3 months after stereotactic, posteroventral pallidotomy. Idiopathic PD was diagnosed on the basis of clinical evaluation and response to medications. Motor disabilities were evaluated according to the Hoehn and Yahr classification,[18] as well as with a number of other measures. All patients had previously been followed in the Indiana University Movement Disorder Clinic and were not adequately controlled by aggressive medical management. Antiparkinsonian medications were not changed from 2 months prior until 3 months after surgery.

All patients were classified into two groups according to their neurologic stages. Patients who had Hoehn and Yahr classifications II and III were placed in the Moderate group (19 patients; 62.7 ± 7.9 years). Patients with Hoehn and Yahr classifications IV and V were included in the Severe group (12 patients; 64.1 ± 8.6 years). Our study was conducted in accordance with the tenets of the Declaration of Helsinki and was approved by the institutional review board. Written informed consent was obtained from patients after the procedure was explained to them.

Stereotactic, Posteroventral Pallidotomy

To improve localization of cells in the globus pallidus interna by increasing their firing rates, surgery was performed after withholding all antiparkinsonian medications for 12 hours. Stereotactic coordinates were determined by magnetic resonance imaging using a stereotactic frame (Radionics). We used electrophysiological microelectrode recording and techniques essentially identical to those reported by Baron et al.[12] to identify cells in the globus pallidus interna. The localization was verified by determining the voltage necessary to activate the pyramidal tract through the lesioning macroelectrode (RFG-3C Graphics Lesion Generator System, Radionics). Radiofrequency lesions (75°C, 75 seconds) were then placed in the globus pallidus interna. One to four unilateral lesions were made for each patient.

Eye Movements

Subjects were seated 1 meter from a target array where a green light-emitting diode was illuminated at 1 of 7 locations (±15°, ±10°, ±5°, and 0°). Horizontal eye movements were recorded binocularly using infrared spectacles (OBER2 system) and digitized at 250 Hz for off-line analysis. A head restraint discouraged head movements. Four saccadic tasks were presented (visually guided, predictable, anti-saccade, and memory-guided). A calibration trial preceded each saccadic task.

Visually Guided Task. The target moved unpredictably from center to one of the other six positions and, after an unpredictable time interval (1.4–2.4 seconds), returned to center. This was carried out 54 times. Subjects were asked to follow the target jumps as rapidly as possible.

Anti-Saccade Task. The target moved unpredictably from center to ±10°. The time interval between target jumps varied randomly over the interval of 2.4 to 4 seconds. Subjects were asked not to follow the target jumps but to look in the opposite direction at an equal distance from center. There were 20 anti-saccade trials.

Memory-Guided Task. Subjects were asked to fixate on the central point while an eccentric flash (50-msec duration) occurred at one of the other six positions after an unpredictable time interval (1.4–2.4 seconds). Subjects were asked to continue to fixate on the central point until it was switched off after an additional delay (1–1.6 seconds). They were then to look at the remembered position of the flash. The trial was carried out 20 times.

Predictable Task. The target hopped back and forth from ±15° with frequency 1 Hz. Subjects were asked to follow the target.

The initial horizontal saccades occurring within 100 to 600 msec after target jumps for the visually guided and anti-saccade tasks (or after fixation point offset for the memory-guided task) were studied. For the predictable task, we analyzed the initial horizontal saccades occurring from 125 msec before to 600 msec after target jumps. For all tasks, there were an equal number of rightward and leftward target movements.

Data Analyses

Data analysis was carried out using interactive programs written in Matlab and Microsoft Visual C++. The digitized eye position signal was differentiated. The algorithm for saccade identification was based on a combination of the Kalman filter algorithm[19] and an algorithm for defining the saccade threshold. Data from the right eye were used. We fitted the amplitude and peak velocity data with an exponential equation (main sequence[20]), $V = B * (1 - \exp[-C * A])$, where B and C are constants, using a least-squares regression algorithm. This equation was used to calculate the peak velocity for an idealized 15° saccade as $V15 = B * (1 - \exp[-C * 15])$. The advantage of this method is that all saccades contribute to this calculated peak velocity. The saccades were separated into several subgroups depending on task, direction, timing of initiation, and target predictability. Mean latency (L), accuracy (A), and peak velocity at 15° (V15) were calculated for each subject and each saccade subgroup. These parameters, whose means were calculated for each patient, were used for statistical analysis.

Statistical Analysis

Comparisons of the saccadic parameters between different subgroups of saccades (pre- versus postsurgical, toward and away from the side of lesions, and between the different paradigms) were made using Wilcoxon signed rank test for repeated measures and were done independently for the Moderate and Severe groups. Comparisons of saccadic parameters between Moderate and Severe used the Mann–Whitney U test. The significance level was set at $P < 0.05$ with the Bonferroni correction factor when necessary.

Results

Figures 1 through 6 show eye movement recordings for the different paradigms before and after surgery for one patient. Patient X was a 65-year-old female who was moderately affected by PD (Hoehn and Yahr III). The lesions were made on her left side.

Visually Guided Saccade Task

Figure 1 shows eye movement recordings during the visually guided saccadic task. We considered the centrifugal and centripetal saccades separately. Centripetal movements were partially predictable because the future position of the target (0°), but not its timing, was known; in addition, other possible differences might exist between centripetal and centrifugal saccades due to differences in innervation patterns and initial conditions of the orbital plant. Figure 2 presents corresponding pre- and postsurgical peak velocity versus amplitude relationships for leftward and rightward centrifugal saccades. The means and standard deviations of latency, accuracy, and V15 for centrifugal and centripetal saccades 1 month before and 3 months after pallidotomy for the Moderate and Severe groups are shown in Table 1. The latencies were slightly increased in the Severe group compared with the Moderate group. Pallidotomy did not significantly change the parameters of centrifugal and centripetal saccades.

Memory-Guided Task

We defined correct responses as initial saccades toward the location of the eccentric flash made after fixation point offset. The fraction of correct saccades was calculated as the number of the correct saccades divided by the number of trials. The

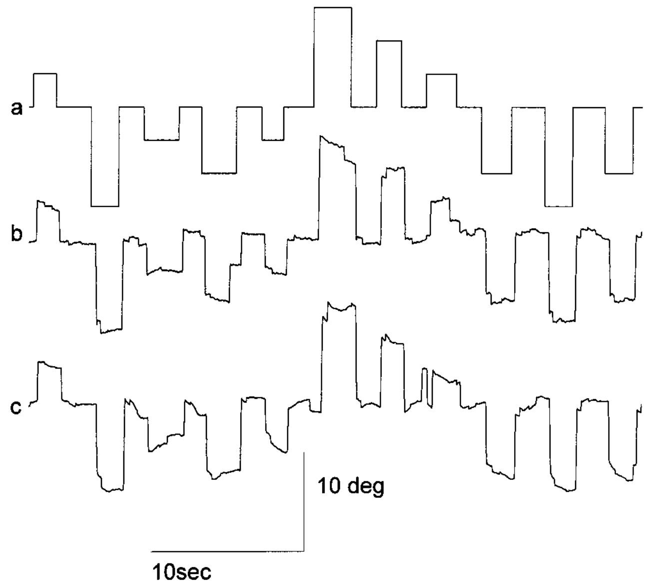

FIGURE 1. Eye movements during visually guided saccadic task. (**a**) Target position; (**b**) position of right eye, presurgical record; (**c**) position of right eye, postsurgical record.

means and standard deviations of the fraction of correct saccades (for the Moderate and Severe groups), latency, and *V*15 of correct saccades (for the Moderate group) 1 month before and 3 months after pallidotomy are presented in Table 2. Mean latency and *V*15 were not calculated for the Severe group, because the average number of correct saccades was too small for reliable statistical analysis. The fraction of correct saccades was significantly greater in the Moderate group. There were no significant differences in the fraction of correct saccades and mean latency before versus after pallidotomy. *V*15 decreased after pallidotomy, although the difference did not reach the level of statistical significance ($P = 0.09$).

Anti-Saccade Task

Figure 3 presents eye movement recordings during the anti-saccade task. We calculated the fraction of correct saccades as the number of saccades opposite to the target jumps divided by the number of target jumps. We also calculated the fraction of reflexive saccades made in the direction of the target jump divided by the number of target jumps (Fig. 3). At times patients made no horizontal saccades. The fraction of "no movement after target jump" corresponded to the remainder 1 –"correct" –"reflexive." Figure 4 shows the corresponding pre- and postsurgical peak velocity versus amplitude relationships for leftward and rightward correct saccades. The means and standard deviations of fraction of correct and reflexive saccades (for the Moderate and Severe groups), latency, and *V*15 of correct saccades (for the Moderate group) 1 month before and 3 months after pallidotomy are presented in Table 3. The number of correct saccades in the Severe group was too few for reliable analysis. The fraction of correct saccades was significantly greater and the fraction of reflexive saccades significantly less in the Moderate versus the Severe group. There were no statistically significant changes in the fraction of reflexive saccades or in latency after pallidotomy. The fraction of correct saccades after pallidotomy in the Moderate group decreased, but the difference did not quite reach the level of statistical significance ($P = 0.06$). The *V*15 decreased significantly after pallidotomy.

Predictable Task

Figure 5 shows eye movements during the predictable task. Histograms of the latency of the saccades were bimodal because many saccades were not generated in response to stimulus presentation but instead predicted future target movement. Therefore, we separated the saccades into two groups: early (predictive) and late (visually guided). The cutoff of 80 msec was chosen as a separation point based on latency histograms. The early group included saccades initiated from 125 msec before to 80 msec after target jumps. The late group included saccades initiated in the interval 80 to 600 msec after target jumps.[21] On average, mean + 2 * SD of early saccade latency was <80 msec, and mean − 2 * SD of late saccade latency was >80 msec, supporting the separation of the responses on this task into two categories. Figure 6 presents the corresponding pre- and postsurgical peak velocity versus amplitude relationships for leftward and rightward early saccades. The means and standard deviations of latency, accuracy, and *V*15 for the early and late saccades 1 month before and 3 months after pallidotomy for the Moderate and Severe groups are presented in Table 4. The relative proportion of early to late saccades was 1:2.

Early Saccades. There were no significant differences between the patient groups for mean latency, *V*15, and accuracy. Latency did not change significantly after pallidotomy. In contrast, *V*15 decreased significantly after pallidotomy in both groups. There was a trend ($P = 0.07$) toward decreased accuracy after pallidotomy in the Moderate group.

Late Saccades. Pallidotomy did not change significantly any parameters of late saccades. We also compared the param-

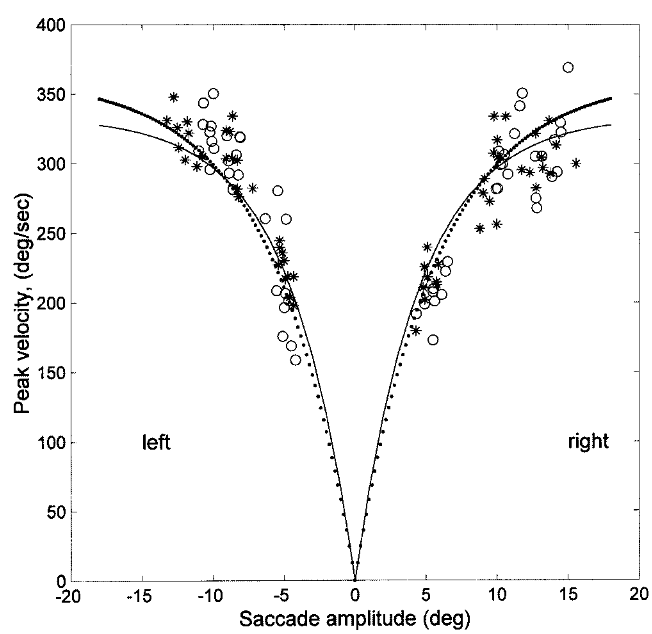

FIGURE 2. Peak velocity versus amplitude relationships for centrifugal saccades (data from both eyes were combined). (*), Pre- and (○), postsurgical saccades. *Solid* and *dotted lines* correspond to the calculated best-fit curves $V = B * (1 - \exp[-C * A])$ pre- and postsurgical, respectively. Side of the lesions: left.

Table 1. Visually Guided Saccadic Task

Saccadic parameters	Moderate		Severe	
	Before Pallidotomy	After Pallidotomy	Before Pallidotomy	After Pallidotomy
Centrifugal				
Latency (msec; mean ± SD)	222 ± 52[a]	225 ± 66[b]	263 ± 43[a]	268 ± 37[b]
Accuracy (mean ± SD)	0.74 ± 0.17	0.73 ± 0.18	0.68 ± 0.17	0.74 ± 0.14
*V*15 (mean ± SD)	370 ± 76	373 ± 49	366 ± 77	347 ± 68
Centripetal				
Latency (msec; mean ± SD)	190 ± 51[c]	192 ± 50[d]	232 ± 40[c]	228 ± 39[d]
Accuracy (mean ± SD)	0.72 ± 0.15	0.71 ± 0.20	0.68 ± 0.15	0.70 ± 0.17
*V*15 (mean ± SD)	447 ± 87	429 ± 94	403 ± 73	420 ± 98

The means and standard deviations of latency, accuracy, and *V*15 (velocity of 15° amplitude saccades from the best-fit logarithm curve) are presented for centrifugal and centripetal saccades before and 3 months after pallidotomy. Moderate and Severe include patients with Hoehn and Yahr II–III and IV–V, respectively. The mean latencies of Severe patients are greater than the mean latencies of Moderate patients (compare [a] $P = 0.025$; [bcd] $P < 0.01$, respectively; Mann–Whitney U test).

Table 2. Memory-Guided Task

Saccadic Parameters	Moderate		Severe	
	Before Pallidotomy	After Pallidotomy	Before Pallidotomy	After Pallidotomy
Correct (mean ± SD)	0.66 ± 0.31[a]	0.63 ± 0.27[b]	0.35 ± 0.23[a]	0.36 ± 0.22[b]
Latency (msec; mean ± SD)	321 ± 74	338 ± 50	—	—
*V*15 (mean ± SD)	335 ± 78	306 ± 54	—	—

The means and standard deviations of fraction of correct saccades, latency, and *V*15 (correct saccades) are presented. The fractions of correct saccades are greater in Moderate versus Severe ($P < 0.01$, compare [ab], respectively).

Table 3. Anti-Saccade Task

Saccadic Parameters	Moderate		Severe	
	Before Pallidotomy	After Pallidotomy	Before Pallidotomy	After Pallidotomy
Correct (mean ± SD)	0.64 ± 0.18[a]	0.52 ± 0.20[b]	0.21 ± 0.18[a]	0.22 ± 0.16[b]
Reflex (mean ± SD)	0.32 ± 0.15[c]	0.38 ± 0.13[d]	0.50 ± 0.23[c]	0.58 ± 0.15[d]
Latency (msec; mean ± SD)	433 ± 140	410 ± 119	—	—
*V*15 (mean ± SD)	375 ± 100[e]	304 ± 103[e]	—	—

The means and standard deviations of correct (fraction of saccades made to the direction opposite to target), reflex (the fraction of saccades made to target), latency, and *V*15 (correct saccades) are presented. After pallidotomy *V*15 decreased ($P < 0.01$, compare [e]). The fraction of correct saccades is greater and the fraction of reflexive saccades is less in Moderate versus Severe (compare [c] $P = 0.03$; [abd] $P < 0.01$, respectively).

Table 4. Predictable Saccadic Task

Saccadic Parameters	Moderate		Severe	
	Before Pallidotomy	After Pallidotomy	Before Pallidotomy	After Pallidotomy
Early				
Latency (msec; mean ± SD)	−31.6 ± 16	−36.7 ± 15	−38.2 ± 15	−35.5 ± 17
Accuracy (mean ± SD)	0.55 ± 0.29	0.42 ± 0.21	0.44 ± 0.11	0.42 ± 0.13
*V*15 (mean ± SD)	366 ± 80[a]	305 ± 99[a]	339 ± 65[b]	289 ± 86[b]
Late				
Latency (msec; mean ± SD)	187 ± 34	187 ± 47	206 ± 37	204 ± 45
Accuracy (mean ± SD)	0.58 ± 0.25	0.48 ± 0.22	0.47 ± 0.12	0.51 ± 0.13
*V*15 (mean ± SD)	387 ± 94	363 ± 83	362 ± 43	336 ± 84

The means and standard deviations of latency, accuracy, and *V*15 of early (125 msec before to 80 msec after target jumps) and late (80–600 msec after target jumps) before and 3 months after pallidotomy are presented. After pallidotomy *V*15 of early decreased significantly in Moderate and in Severe ($P = 0.04$, compare, respectively[ab]). There are no statistically significant differences between Moderate and Severe.

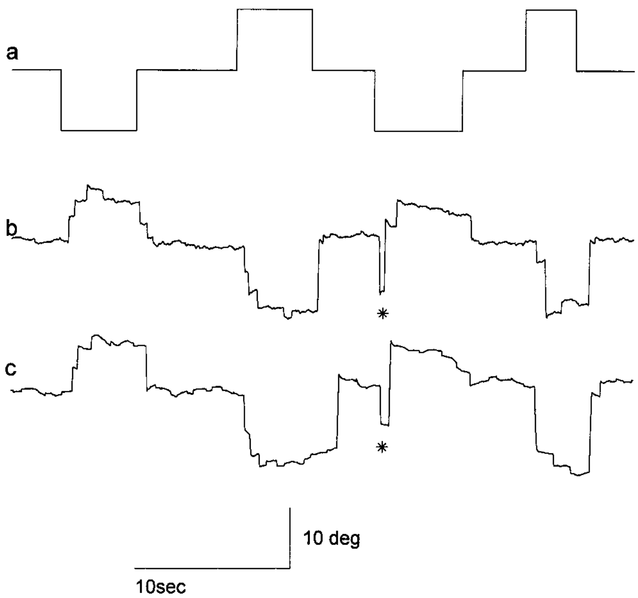

FIGURE 3. Eye movements during anti-saccade task. (**a**) Target position; (**b**) position of right eye, presurgical record; (**c**) position of right eye, postsurgical record. *Asterisk* indicates an incorrect response.

eters of leftward versus rightward saccades. There were no significant directional differences in latency, accuracy, or *V*15 for early or late saccades.

Comparisons of Parameters of Contralateral versus Ipsilateral Centrifugal, Centripetal, Early and Late Saccades. We separated centrifugal, centripetal, and early and late saccades in the Moderate group into contralateral (away from

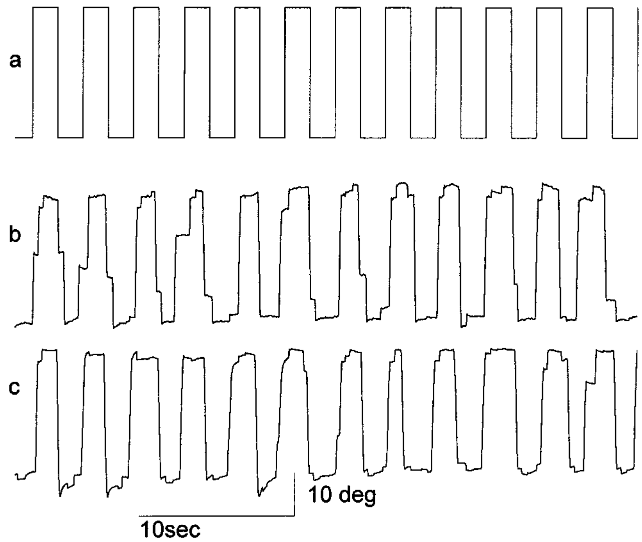

FIGURE 5. Eye movements during predictable task. (**a**) Target position; (**b**) position of right eye, presurgical record; (**c**) position of right eye, postsurgical record.

the side of the lesions) and ipsilateral (toward the side of the lesions) subsets and compared their saccadic parameters.

Centrifugal, Centripetal, and Late Saccades. There was no difference between latency, accuracy, or *V*15 of contralateral versus ipsilateral saccades before and after pallidotomy for centrifugal, centripetal, and late saccades. Figure 2 is a good illustration of the similarity between peak velocity versus amplitude relationships of centrifugal saccades for pre- and postsurgical, contralateral and ipsilateral saccades.

Early Saccades. There was no difference between latency or accuracy of contralateral versus ipsilateral saccades

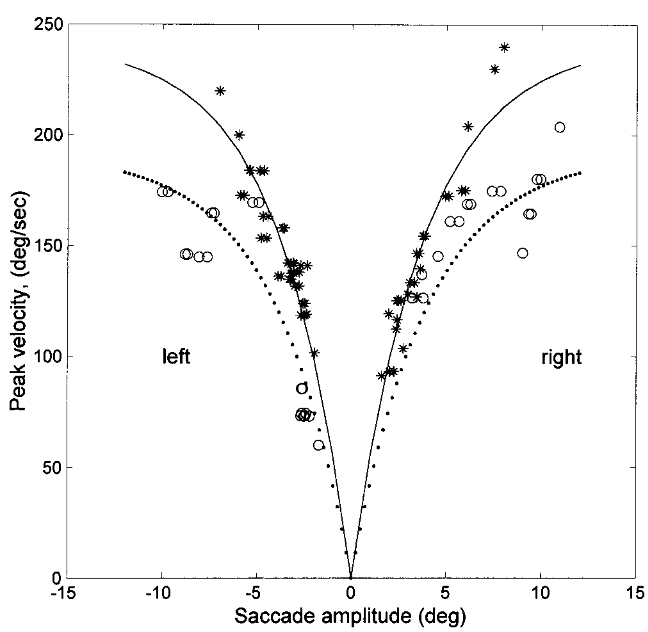

FIGURE 4. Peak velocity versus amplitude relationships for anti-saccades (data from both eyes were combined). (*), Pre- and (○), postsurgical saccades. *Solid* and *dotted lines* correspond to the calculated best-fit curves $V = B * (1 - \exp[-C * A])$ pre- and post-surgically respectively. Side of the lesions: left. Note that peak velocity decreased after surgery.

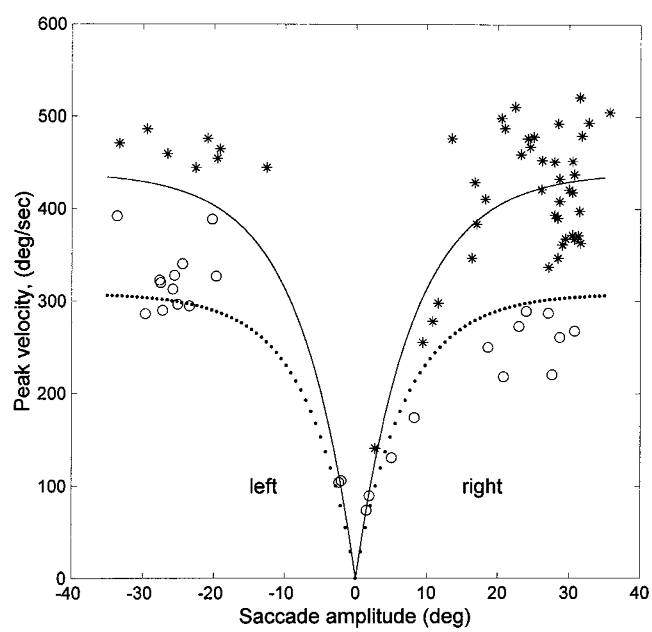

FIGURE 6. Peak velocity versus amplitude relationships for early saccades (data from both eyes were combined). (*), Pre- and (○), postsurgical saccades. *Solid* and *dotted lines* correspond the calculated best-fit curves $V = B^*(1 - \exp[-C * A])$ pre- and postsurgically, respectively.

before or after pallidotomy. Before pallidotomy, the *V*15 of ipsilateral saccades was greater than *V*15 of contralateral saccades. After pallidotomy *V*15 of ipsilateral and contralateral saccades both decreased ($P < 0.05$ and $P = 0.07$, respectively). There was no difference in *V*15 of contralateral versus ipsilateral saccades after pallidotomy. Patient X (Fig. 6) illustrates the slightly decreased *V*15 after pallidotomy, both for contralateral and ipsilateral saccades.

We did not statistically compare the ipsilateral and contralateral saccades in anti-saccade and memory-guided tasks because of the small numbers of saccades in each subset. However, as indicated in Figure 3, we did not find obvious differences between ipsilateral and contralateral saccades.

Comparison of Parameters of Centrifugal, Centripetal, Early, Remembered, and Anti-Saccades. Centrifugal and centripetal saccades had different saccadic characteristics. Latency was greater and *V*15 was less for centrifugal than for centripetal saccades in both patient groups both before and after pallidotomy ($P < 0.01$). We evaluated the means and standard deviations of the ratios $V15_{\text{remembered}}/V15_{\text{centrifugal}}$, $V15_{\text{early}}/V15_{\text{centrifugal}}$, and $V15_{\text{anti-saccade}}/V15_{\text{centrifugal}}$ for the Moderate group. The mean values ± SDs were, respectively, 0.96 ± 0.22, 1.0 ± 0.27, and 0.95 ± 0.2 before pallidotomy and 0.82 ± 0.16, 0.82 ± 0.26, and 0.80 ± 0.29 after. Thus, before pallidotomy, the *V*15 was similar for centrifugal, remembered, early, and anti-saccades, whereas after pallidotomy, *V*15 of centrifugal saccades was significantly greater than *V*15 of remembered, early, and anti-saccades.

Discussion

Based on our four saccadic tasks, we evaluated three types of visually guided saccades (centrifugal and centripetal saccades from the visually guided task and late responses from the predictable task) and three types of internally mediated saccades (remembered, anti-saccades and early responses from the predictable task). Our findings, that visually guided saccades in advanced PD were not impaired when compared with moderate PD, agree with those of other previously reported studies.[2,3,7–10] Only in advanced PD did saccadic latency increase slightly. No parameters of the three types of visually guided saccades were affected by pallidotomy. Our results imply that neither PD nor pallidotomy affects the pathways that control saccades made in response to the appearance of a visual stimulus. Internally mediated saccades, generated in response to internal cues rather than in response to such an external stimulus, were more impaired in patients with advanced PD compared with moderate PD, as observed previously.[6,8] The Severe patient group had greater difficulty suppressing reflexive saccades in the anti-saccade task and generating correct saccades in the anti-saccade and remembered tasks than did the Moderate patients. After pallidotomy there was a small decrease in the fraction of correct saccades in the Moderate group (Table 3). If this trend does represent an actual worsening, the worsening could be due either to the surgery or to progression of the underlying disease during the 4-month interval between tests. A randomized study would help to distinguish between these possibilities. The same possibilities hold for the small decrease in the accuracy of early saccades in the predictable task. Although we had too few correct responses from severely affected patients to evaluate the point ourselves, another study[8] reported that velocities in the anti-saccade task do not decrease significantly with the progression of PD. Therefore, based on the results obtained from the Moderate group in our study, we can conclude that pallidotomy does not change latency but rather that it may reduce accuracy and more likely decreases the velocity of all three types of internally mediated saccades (early, remembered, and anti-saccades). In normal subjects, visually guided saccades are 10% to 20% faster than remembered, predictive, or anti-saccades.[22,23] A similar difference in velocities was not observed in our PD patients before pallidotomy. After pallidotomy, the *V*15 of visually guided saccades did not change, whereas the *V*15 of internally mediated saccades decreased (approximately 10%–20%). The observed decrease of velocity of internally mediated saccades was the change in the saccadic parameters most clearly associated with pallidotomy.

We can speculate about the processes leading to the decrease of velocity. The projection from the frontal eye field (FEF) to the superior colliculus (SC) via the caudate nucleus and substantia nigra pars reticulata (SNpr) is associated with saccades elicited by an internal trigger rather than generated as a reflexive response to a novel visual stimulus; this category includes remembered, predictive, and anti-saccades[24–26] (Fig. 7). A possible explanation of the decreased velocity of internally mediated saccades is that pallidotomy facilitated the neuronal activities in SNpr and increased the tonic inhibition of SC. In this case, we would expect to find an asymmetry (contralateral versus ipsilateral) of saccadic characteristics after pallidotomy similar to the asymmetry observed in monkeys with local dopamine depletion in the caudate nucleus.[27] However, we did not find a significant difference between the parameters (latency, accuracy, and *V*15) of contralateral versus ipsilateral early, late, centrifugal, and centripetal saccades after pallidotomy. The *V*15s of early responses on the predictive task decreased both for contralateral and ipsilateral saccades after pallidotomy. A PET study found that the lentiform nuclei (including putamen and globus pallidus) and thalamus were activated consistently during one type of internally mediated saccade (the repetition of a saccade sequence).[16,28] Patients with chronic bilateral lesions affecting the putamen and/or pallidum showed deficits in memory-guided and predictive saccades; visually guided saccades were not affected.[29] The putamen and globus pallidus may belong to a subsystem projecting (via the thalamus) to frontal areas involved in the control of saccades.[30] Nevertheless, the lack of asymmetry of saccades after unilateral pallidotomy in our study is unexplained.

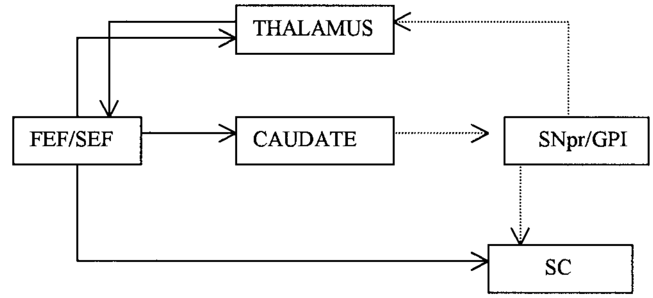

Figure 7. Simplified diagram of ocular motor projections. FEF, frontal eye field; SEF, supplementary eye field; GPI, internal segment of globus pallidus. *Dotted lines* correspond to inhibitory projections.

Although the motor circuit involving the basal ganglia and thalamus plays an important role in the control of movements, changes in motor functions after pallidotomy have occurred primarily during "off" period studies[12–14,17] (i.e., when antiparkinsonian medications have been withheld or were not effective). The insignificant change of many saccadic parameters reported here may in part be due to the fact that our patients were tested during "on" periods. Testing of saccadic eye movements during "off" periods before and after pallidotomy may be a more sensitive indicator of treatment-related change.

In conclusion, our study confirmed previous observations that there are no or only slight abnormalities of visually guided saccades in patients with moderate and severe PD and that patients with severe PD have more impaired internally mediated saccades compared with those with moderate PD. In addition, we have demonstrated that unilateral pallidotomy does not affect visually guided saccades but does significantly decrease the peak velocity and, possibly, the accuracy of internally mediated saccades. This is in contrast to the improvements in other motor functions seen after this procedure.[12–14] However, the mechanism of these effects is not known. A control group of matched nonsurgical patients and longer-term follow-up of our patients 1 or 2 years after surgery might answer these questions.

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