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Saccadic Eye Movements Are Related to Turning Performance in Parkinson Disease

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1 **Abstract**

2 *Background.* Persons with Parkinson disease (PD) experience difficulty turning, leading to  
3 freezing of gait and falls. We hypothesized that saccade dysfunction may relate to turning  
4 impairments, as turns are normally initiated with a saccade. *Objective.* Determine whether  
5 saccades are impaired during turns in PD and if characteristics of the turn-initiating saccade are  
6 predictive of ensuing turn performance. *Methods.* 23 persons with PD off medication and 19  
7 controls performed 90 and 180 degree in-place turns to the right and left. Body segment  
8 rotations were measured using 3-D motion capture and oculomotor data were captured using a  
9 head-mounted eye tracking system and electrooculography. Total number of saccades and the  
10 amplitude, velocity, and timing of the first saccade were determined. *Results.* Turn performance  
11 (turn duration, number of steps to turn) was impaired in PD ( $p < 0.05$ ). PD performed more  
12 saccades, and the velocity and timing of the first saccade was impaired for both turn amplitudes  
13 ( $p < 0.05$ ). Amplitude of the first saccade was decreased in PD during 180 degree turns. Turn  
14 duration correlated with oculomotor function. Characteristics of the first saccade explained 48%  
15 and 58% of the variance in turn duration for 90 and 180 degree turns, respectively. *Conclusions.*  
16 Turning performance is impaired in PD and may be influenced by saccade dysfunction. An  
17 association between saccade function and turning performance may be indicative of the key role  
18 of saccades in initiating proper turning kinematics. Future work should focus on improving  
19 saccade performance during functional tasks and testing the effects of therapeutic interventions  
20 on related outcomes.

21 **Keywords:** Parkinson Disease, Saccades, Oculomotor Dysfunction, Gait, Turning

22

23

24 **INTRODUCTION**

25           Parkinson disease (PD) is a progressive neurodegenerative disease that is associated with  
26 a reduction in mobility, with problems that include difficulty turning. Turning difficulties can  
27 lead to freezing of gait (FOG), falls, fear of falling, and social withdrawal.<sup>1-3</sup> Falls that occur  
28 during turning are eight times more likely to result in hip fracture than falls during straight line  
29 walking.<sup>4</sup> Furthermore, individuals with PD have a 3.2 fold greater risk of hip fracture than age-  
30 matched individuals without PD.<sup>5</sup> In addition to the large personal cost of turning difficulties,  
31 hip fractures represent a substantial financial burden to society, with the cost of hip fracture care  
32 in individuals with PD totaling approximately \$192 million per year in the United States.<sup>5,6</sup>

33           Studies focusing on turning have noted that individuals with PD require more steps and  
34 take longer to complete a turn than healthy controls.<sup>7-11</sup> Those with PD who report turning  
35 difficulty also have a higher incidence of freezing of gait and falls.<sup>10,12</sup> Furthermore, the timing  
36 of segmental rotations during turn initiation is altered in PD. This has been termed “en bloc”  
37 turning and is characterized by the near simultaneous rotation of the head, trunk, and pelvis and  
38 reduced relative rotations between adjacent segments.<sup>9,13-15</sup> Other measures of poor turn quality  
39 have been observed in those with PD including a wider turn arc<sup>16</sup>, narrowed step width<sup>11,16,17</sup>,  
40 and higher variation in step duration compared with controls.<sup>16</sup>

41           It is evident that visual information plays an important role in the control of locomotion  
42 and turning. Clear differences in gaze behavior and stepping performance have been  
43 demonstrated between older adult fallers and non-fallers.<sup>18</sup> In addition, training of eye  
44 movements has been shown to improve locomotor performance in individuals with cerebellar  
45 damage.<sup>19</sup> Several studies in healthy individuals have shown that the eyes participate in a top-  
46 down rotation sequence such that the eyes are the first to turn, followed by the head, trunk, and

47 then the feet.<sup>20-23</sup> The initial saccade during a turn, in combination with subsequent head  
48 movements, provides a shift of gaze to a position aligned with the direction of travel. Gaze shifts  
49 precede shifts in center of mass (COM) trajectory during turning and unexpected perturbations of  
50 gaze cause delays in COM movement to steer the body along the desired trajectory.<sup>24</sup>

51 While eye movements have been measured in healthy adults during turning tasks, it is  
52 unclear how eye movements relate to turning performance in individuals with PD. During head-  
53 fixed tasks, saccadic eye movements have been shown to be abnormal in those with PD,  
54 including prolonged fixation times, bradykinesia, and akinesia during rapid alternating gaze  
55 shifts between two fixed targets.<sup>25</sup> Several more recent studies have demonstrated deficits in  
56 control of voluntary saccades in people with PD, consistently noting that saccades are slower and  
57 smaller than those of control subjects.<sup>26-30</sup> Briand et al<sup>29</sup> reviewed a series of 15 studies of  
58 voluntary saccades and noted that all but one of these studies reported voluntary saccade  
59 performance inferior to that of control subjects in individuals with PD. Therefore, we  
60 hypothesize that saccadic eye movements performed during turns are also likely abnormal and  
61 may contribute to impaired turn performance. A disruption of the normal top-down rotation  
62 sequence by poor saccade timing or decreased saccade amplitude may contribute to the altered  
63 turning kinematics reported in those with PD. Hence, the purposes of this study were to  
64 determine whether saccadic eye movements during turning are impaired in individuals with PD  
65 and to determine if characteristics of the saccade that initiates a turn are predictive of ensuing  
66 turn performance.

## 67 **METHODS**

### 68 **Participants**

69           Twenty-three individuals with idiopathic PD and 19 age- and gender-matched controls  
70 participated in this investigation. Individuals with PD were recruited from a database of patients  
71 from Washington University School of Medicine’s (WUSM) Movement Disorders Center.  
72 Control participants were recruited from the Volunteers for Health Database, posted flyers, and  
73 other healthy volunteer databases associated with WUSM. All subjects met the following  
74 inclusion criteria: aged 30 years or older, normal central (except for PD in the PD group) and  
75 peripheral neurological function, able to stand independently for at least 30 minutes and walk  
76 independently without an assistive device, no history of vestibular disease and no evidence or  
77 history of dementia. Exclusionary criteria included: any serious medical condition other than  
78 PD, use of neuroleptic or other dopamine-blocking drug, use of drug that might affect balance  
79 such as benzodiazepines, evidence of abnormality on brain imaging (previously done for clinical  
80 evaluations-not part of this research), history or evidence of other neurological deficit, such as  
81 previous stroke or muscle disease, and history or evidence of orthopedic, muscular, or  
82 psychological problem that may affect task performance during the study. Additionally,  
83 participants with PD were included based on a diagnosis of “definite PD” by a board certified  
84 neurologist, as previously described by Racette et al. (1999) based upon established criteria  
85 (Calne et al. 1992, Hughes et al. 1992) and were excluded if they had received surgical  
86 management of PD (e.g. pallidotomy or deep brain stimulation). All subjects gave informed  
87 consent to perform experimental procedures approved by the Human Research Protection Office  
88 at WUSM.

## 89 **Experimental Procedures**

90           All study procedures were performed in the Locomotor Control Laboratory at WUSM.  
91 Participants with PD were tested OFF medication, i.e. after a 12-hour withdrawal of all anti-

92 Parkinson medications. Before testing procedures commenced, the Movement Disorder Society  
93 Unified Parkinson's Disease Rating Scale (MDS-UPDRS) Motor Subscale III was administered  
94 according to Goetz et al<sup>31</sup> by a trained rater. The MDS-UPDRS-III is a measure of severity of PD  
95 motor symptoms, as well as physical disability, and includes measures of rigidity, gait, tremor,  
96 hand/arm and leg movements (bradykinesia), speech, and facial expressions. The modified  
97 Hoehn and Yahr scale also was used to evaluate disease severity in PD.<sup>32</sup>

98         During the experimental protocol, participants completed in-place turns of 90 degrees and  
99 180 degrees amplitude. Instructions were given to perform the turns in a comfortable and normal  
100 fashion. No specific auditory or visual cues were provided to cue turn onset or completion other  
101 than directing subjects to "turn 90 degrees to face the wall beside you" or "turn 180 degrees to  
102 face the wall behind you", accordingly. Participants were instructed to begin the movement  
103 anytime after receiving the turn direction instruction of left or right for the given trial. Turns  
104 were completed to both the right and left in randomized order and all 90° turns were completed  
105 prior to beginning the block of 180° turns. Participants completed a minimum of 5 turns in each  
106 direction. Data quality was visually monitored in real time and additional turns were completed  
107 as needed to insure an adequate number of quality trials for analysis.

108         Full body kinematic data were captured using an eight camera, passive marker, 3-  
109 dimensional, high-resolution motion capture system (Motion Analysis Corporation, Santa Rosa,  
110 CA) sampling at 100 Hz in Cortex software (Motion Analysis Corporation, Santa Rosa, CA).  
111 Thirty-eight retro-reflective markers were positioned on the head (top of head, back of head, left  
112 ear, right ear), trunk (left and right acromion, right scapula, sternal notch, xyphoid process, 7<sup>th</sup>  
113 cervical vertebra, 12<sup>th</sup> thoracic vertebra), pelvis (left and right anterior superior iliac spine, left  
114 and right posterior superior iliac spine, sacrum), both legs (greater trochanter, anterior thigh,

115 medial and lateral femoral condyle, tibial tuberosity, front of shank, medial and lateral malleolus)  
116 and both feet (calcaneus, navicular, distal 2<sup>nd</sup> metatarsal). Oculomotor data were captured using a  
117 head-mounted infrared binocular eye tracking system (Applied Sciences Laboratory, Bedford,  
118 Ma) and electrooculography (EOG). Oculomotor data were captured synchronously at 1000Hz  
119 on the same PC workstation with kinematic data in Cortex software.

## 120 **Data Processing**

121 Individual kinematic marker data and analog data were filtered using 4th order low-pass  
122 Butterworth filters. Marker data were filtered in Cortex with a cut-off frequency of 6 Hz while  
123 analog data were filtered in MotionMonitor (Innsport, Chicago, IL) with a cut-off frequency of  
124 20 Hz. Global and segment coordinate systems were defined in MotionMonitor with the positive  
125 X-axis pointing anteriorly, positive Y-axis pointing to the left, and positive Z-axis pointing  
126 upward vertically. Rotations of the head, trunk, pelvis, and feet about global Z were extracted  
127 using a Z-X-Y Euler sequence. Subsequently, kinematic angle data and filtered analog data were  
128 exported for further processing in custom written MATLAB software (The Mathworks, Inc,  
129 Natick, MA).

130 Time of onset for segment rotations (relative to the global coordinate system) was  
131 determined by identifying the first frame at which the rotation reached five degrees above  
132 baseline. Similar criteria were used to identify turn offset, defined as the frame at which the  
133 rotation came within five degrees of maximal, final position. Eye tracker and EOG data were  
134 used to identify and measure saccades occurring just prior to and during turn performance.  
135 Saccades were identified visually and later confirmed to be true saccades if the maximum  
136 velocity of the eye movement exceeded 30 degrees/sec.<sup>33,34</sup> Onsets and offsets of the first  
137 saccade associated with each turn were identified visually. Using these time points, saccade



138 amplitude, peak velocity, and timing of the first saccade relative to head and foot rotations were  
139 calculated. Example trials are shown for an individual with PD and a control in Figure 1.

140 Individual trials were excluded from analysis if eye position or body segment rotations  
141 about the global Z-axis were not static for at least 1000ms prior to turn onset. Trials were also  
142 excluded if artifacts in oculomotor data due to blinks, prolonged closure of eyelids, or other  
143 factors precluded measurement of the initial saccade. Remaining trials within a condition (90 or  
144 180 degrees) were averaged to obtain a single data point for each subject. Left and right turns  
145 were combined for analysis as turn performance did not differ between leftward and rightward  
146 turns.

#### 147 **Data Analysis**

148 Independent Student's t-tests were used to compare between-group differences in turn  
149 performance and oculomotor performance during both 90 and 180 degree turns. Our primary  
150 variables of interest were the amplitude and velocity of the saccade initiating the turn, the total  
151 number of saccades performed during the turn, and the timing of the first saccade relative to  
152 onsets of head and foot rotations. The latencies between the first saccade and head/foot rotations  
153 were normalized to the duration of the first gait cycle and are reported as a percentage of the first  
154 gait cycle time. We also employed a linear regression model with turn duration as the dependent  
155 variable and number of saccades, initial saccade velocity and normalized timing of the saccade  
156 relative to turn onset as the independent variables to identify the amount of variance in turn  
157 performance accounted for by characteristics the saccade initiating the turn. Saccade amplitude  
158 and the normalized timing of the saccade relative to head rotation onset were not included in the  
159 model as they were highly correlated with the included variables. The criterion for statistical  
160 significance was set at  $p < 0.05$ .

161 **RESULTS**

162 Demographic data are displayed in Table 1. Data from three participants included in the  
163 90 degree turn analysis could not be included in the analysis for the 180 degree turn due to poor  
164 oculomotor data quality. Conversely, one participant was included in the 180 turn analysis but  
165 omitted from the 90 degree analysis for similar reasons. Regardless of turn type, age did not  
166 differ between PD and controls.

167 Turn performance was impaired in PD compared with controls, with both 90 and 180  
168 degree turns requiring more steps ( $p < 0.05$ ) and a greater time to complete ( $p < 0.01$ ). PD also  
169 performed a greater number of saccades during their turns, and the peak velocity of the initial  
170 saccade was slower in PD for both 90 and 180 degree turns ( $p < 0.01$ ). The amplitude of the  
171 initial saccade was less in PD than in controls for 90 degree turns only ( $p < 0.01$ ). The normalized  
172 latency between start of the first saccade and start of the first step (Norm E-F Index) was  
173 different between groups, with PD performing the first saccade earlier relative to the onset of  
174 foot rotation ( $< 0.05$ , Table 2).

175 The number of saccades, initial saccade amplitude, initial saccade velocity, and Norm E-  
176 F Index were all significantly correlated with turn duration (Figure 2). Turn duration, which was  
177 highly correlated with the number of steps required to turn, was used as the dependent variable  
178 representing turn performance in our regression analysis. The linear regression model, which  
179 included both PD and controls, explained a significant amount of the variance in turn duration  
180 for both 90 degree ( $R^2 = .481$ ,  $F(3,27) = 11.4$ ,  $p < .001$ ) and 180 degree ( $R^2 = .578$ ,  $F(3,25) = 16.0$ ,  
181  $p < .001$ ) turns. Table 3 reports the unstandardized (B) and standardized ( $\beta$ ) regression  
182 coefficients for these models.

183 Comparing freezers and non-freezers, turn duration and number of steps were greater in  
184 subjects who reported freezing of gait at least once per week on item 3 of the FOG questionnaire  
185 ( $p < 0.05$ ). Mean values for initial saccade velocity and Norm E-F Index differed between  
186 freezers and non-freezers, but these comparisons did not reach statistical significance. Despite  
187 the lack of statistical significance, the effect sizes, measured using Cohen's  $d$ , were moderate to  
188 large. Effect size for saccade velocity between freezers and non-freezers equaled 0.91 for 90  
189 degree turns and 0.52 for 180 degree turns. Norm E-F Index effect sizes were 0.8 for 90 degrees  
190 turns and 0.86 for 180 degree turns. Number of saccades and initial saccade amplitude were  
191 similar between freezers and non-freezers. Data comparing freezers and non-freezers is presented  
192 in Table 4.

193

## 194 **DISCUSSION**

195 This study sought to determine whether saccadic eye movements performed during  
196 turning are impaired in individuals with PD and to determine if characteristics of the saccade that  
197 initiates a turn are predictive of ensuing turn performance. In confirmation of our hypotheses,  
198 saccadic eye movements were impaired during turning in persons with PD and these  
199 impairments were related to turning dysfunction. Individuals with PD used a greater number of  
200 saccades to complete both 90 and 180 degree turns, the initial saccade was both smaller (180  
201 degrees only) and slower than that of controls, and the timing of the initial saccade relative to the  
202 turn onset was altered in those with PD. Furthermore, turn performance was impaired in persons  
203 with PD and approximately 50% of the variance in turn performance was explained by saccade  
204 performance across all participants. Differences in saccade performance between the 90 and 180  
205 degree turns were largely predictable. The 180 degree turns required approximately twice as

206 many saccades as the 90 degree turns and the amplitude of the initial saccade was similar  
207 between turn magnitudes for both groups. This suggests that the size of the turn-initiating  
208 saccade is constant for turns of 90 degrees and larger, and that simply more saccades are  
209 performed for large turns. Similarly, the delay between the first saccade and turn onset did not  
210 differ between the two turn magnitudes.

211 Previous research widely demonstrates that voluntary saccade performance is impaired in  
212 persons with PD.<sup>25-30</sup> These studies, however, have focused only on simple head-fixed tasks or  
213 on saccades performed in conjunction with head movements from a seated position. Studying the  
214 oculomotor system using simple saccade paradigms has allowed researchers to better understand  
215 basal ganglia disorders using a simple, predictable, and well understood motor system. However,  
216 little information has been gathered from such studies regarding the implications of oculomotor  
217 impairments on functional activities in those with PD. To the best of our knowledge, this is the  
218 first study to report saccade performance during a more complex, functional task in people with  
219 PD. Our novel findings support previous work that voluntary saccades are impaired in PD and  
220 lend support to the idea that the eyes play a key role in turning. The turning sequence has been  
221 characterized in healthy controls and consists of a top-down rotation sequence led by the eyes  
222 and followed by rotations of the head, trunk, pelvis, and feet.<sup>20-23</sup> In individuals with PD this  
223 sequence is impaired, characterized by smaller intersegmental rotations and altered timing of  
224 segment rotations.<sup>9,13,14</sup> The present study reveals that the turning sequence in PD is also  
225 characterized by a longer than normal delay between the first saccade and the initiation of the  
226 gait cycle, as well as a smaller and slower saccade at the beginning of the turn. Functionally, this  
227 manifests in reduced turn performance. As evidenced by the strong correlations between saccade  
228 performance (the number of saccades, saccade velocity, and saccade timing) and turn

229 performance (number of steps and turn duration), the degree of oculomotor impairment may  
230 impact turn quality.

231         Our finding of a greater delay between the initial saccade and the rest of the turning  
232 sequence in the PD group is contrary to our hypothesis. Expanding the PD en-bloc turning  
233 phenomenon to include eye movements, one would expect the eyes to rotate more in sync with  
234 the head, trunk and feet, as opposed to our observation of a longer latency between the eyes and  
235 feet. Our PD group actually performed the first saccade much earlier in the rotation sequence  
236 than did the controls, and the longer latencies were unexpectedly associated with a longer turn  
237 duration and more steps. This finding may be explained by a generalized bradykinesia that  
238 affects both the motor and oculomotor systems. While the basal ganglia are often described as  
239 having distinct loops for oculomotor and motor control, recent evidence suggests an overlap in  
240 control of both eye and limb movements by the subthalamic nucleus (STN), as neurons in the  
241 STN respond to both voluntary saccades and limb movements.<sup>35</sup> Therefore, the greater delay  
242 between eye movement and turn onset seen in PD may be the result of a dysfunctional common  
243 motor pathway responsible for an overall bradykinetic turn sequence. Based on this, deep brain  
244 stimulation (DBS) may prove beneficial for improving turn performance in PD by enhancing  
245 both eye and limb movements. Levodopa therapy, the most common treatment for those with  
246 PD, provides minimal improvement in both turn performance and voluntary saccade  
247 performance.<sup>36,37</sup> However, DBS of the STN in persons with PD has shown considerable  
248 efficacy in improving motor performance, including gait and performance of voluntary and  
249 reflexive saccades.<sup>38-40</sup> However, no studies to date have examined the effect of DBS on turn  
250 performance, nor the effect of DBS on saccade function during functional tasks. Therefore,

251 future work should target the effects of STN-DBS on turn performance and associated  
252 oculomotor performance.

253         Studies extending beyond PD corroborate a relationship between oculomotor dysfunction  
254 and gait impairments; a relationship that appears to be related to risk of falling in a range of  
255 populations. In a study comparing elderly individuals who were at high risk for falling with  
256 those at low risk for falling, a longer delay between horizontal saccade initiation and initiation of  
257 footlift was observed in the high-risk group during a precise walking task.<sup>41</sup> Differences in gaze  
258 behavior have also been shown between adult fallers and non-fallers.<sup>18</sup> In patients with  
259 progressive supranuclear palsy (PSP), those with more severe gaze palsy displayed an altered  
260 stepping pattern when navigating obstacles, placing them at higher risk for trips and falls.<sup>42</sup> In  
261 our study, subjects who reported FOG at least once per week displayed turn performance deficits  
262 and altered saccade timing and velocity, although the comparison of oculomotor measures failed  
263 to reach statistical significance, possible due to the small group sizes. Disease severity (MDS-  
264 UPDRS III) and duration were not different between freezers and non-freezers, illustrating that  
265 FOG is a specific pathology not present in all PD patients regardless of disease stage or severity.<sup>2</sup>  
266 While we did not obtain fall history records in this study, FOG has been shown to be a risk factor  
267 for falling, and thus the freezers in our study likely represent a sample of patients at higher risk  
268 for falls and fall-related injuries. Taken together, our study and those of other pathological  
269 populations suggest a relationship between fall risk and gait/oculomotor function. Therefore,  
270 rehabilitation strategies aimed at decreasing the risk of falls during ambulation, and in particular  
271 during turning, are important.

272         Cueing has received considerable attention over the past decade as a means of improving  
273 temporal and spatial parameters of gait in persons with PD. Rhythmic auditory, visual, and

274 attentional cues have been shown to improve stride length and gait velocity during straight  
275 walking.<sup>43-46</sup> However, the ability of cues to improve turning performance is less well  
276 understood. When rhythmic auditory cues were used during a U-turn task, only step time  
277 variability was improved among a number of turn performance parameters.<sup>16</sup> In contrast, another  
278 study found that rhythmic auditory and somatosensory cues improved turn time in a functional  
279 task (carrying a tray).<sup>47</sup> Clearly, more work is necessary to determine the effect of cues on  
280 turning, and based on the importance of oculomotor function during turning, using cues to  
281 promote a more appropriate oculomotor strategy during turns should be of interest.

282

### 283 **Limitations**

284         One limitation of this study is that saccades were measured using two separate  
285 measurement systems. The infrared binocular eye tracking system served as our primary  
286 measurement tool, with EOG serving a secondary role. Due to the technical nature of measuring  
287 pupil and corneal reflections using the infrared system, quality infrared data could not be  
288 obtained from all participants. In such cases, EOG data were used for analysis. To verify  
289 agreement between these two measurement systems, infrared and EOG data were compared  
290 using data from participants for whom we had both data sets. When comparing the timing,  
291 amplitude, and velocity of the initial saccade, values obtained from the two systems compared  
292 exceptionally well. Therefore, the authors felt confident in pooling data obtained from either  
293 measurement system. Another limitation of this study is that measurement occurred in a  
294 laboratory setting and thus participants were aware that their performance was being monitored.  
295 Hence, it is possible that participants' oculomotor and turning performance may have differed  
296 from their usual performance in a more natural setting. The authors think, however, that such

297 effects are minimal and would have been experienced similarly by both groups, thus not  
298 detracting for our findings.

299

### 300 **Conclusions and Future Directions**

301 It is evident that turning difficulty is a primary trigger for freezing and falls in PD, and  
302 our study indicates that impaired voluntary saccades may contribute significantly to this  
303 problem. Rehabilitative strategies might consider focusing on cueing persons with PD to initiate  
304 turns with a more appropriate top-down rotation sequence, initiated by a large amplitude saccade  
305 prior to commencing the gait cycle. Accordingly, future research should be directed towards  
306 studying the effects of cueing and practice on the ability to improve saccade performance during  
307 turns, and whether such improvements offer meaningful improvements in turn performance and  
308 related fall risk. Additionally, future work may assess the effects of therapeutic interventions  
309 (e.g. deep brain stimulation) on such variables.

310

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475 **FIGURE LEGENDS**

476 **Figure 1. Representative data from individual turn trials showing eye, head, and foot**  
477 **rotations in the horizontal plane.**

478 Panel A: Representative 90 degree turn performed by an individual with PD. The subject  
479 performed 8 saccades of varying amplitudes during the turn, and required 3 steps to complete the  
480 turn. Panel B: Representative 90 degree turn performed by a healthy control. The subject  
481 performed only 5 saccades during the turn and required only 2 steps and less time to complete  
482 the turn than the individual with PD. Panel C: Representative 180 degree turn performed by an  
483 individual with PD. The subject performed 15 saccades of varying amplitudes during the turn,  
484 and required 5 steps to complete the turn. Panel D: Representative 180 degree turn performed  
485 by a healthy control. The subject performed 8 saccades of more consistent amplitude than those  
486 performed by the individual with PD, and required only 4 steps and less time to complete the  
487 turn than the individual with PD.

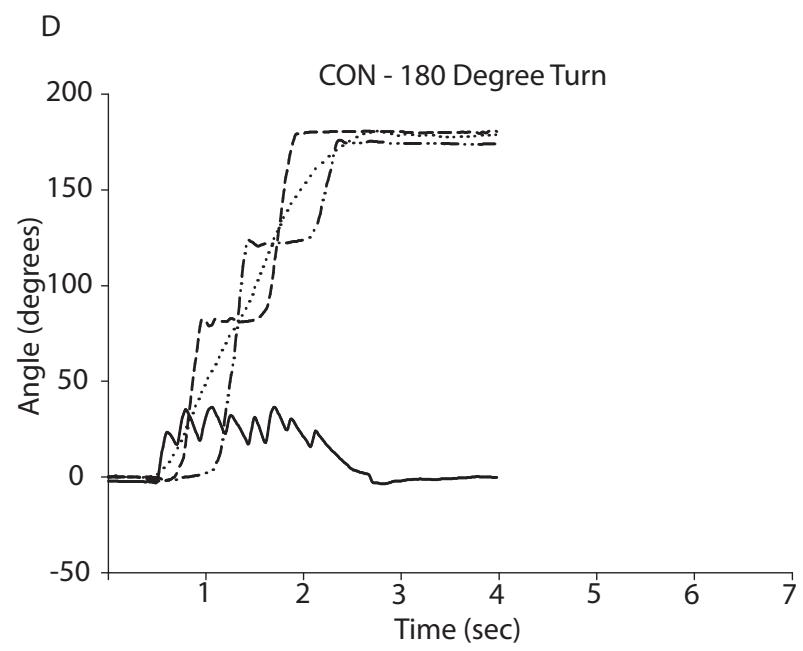
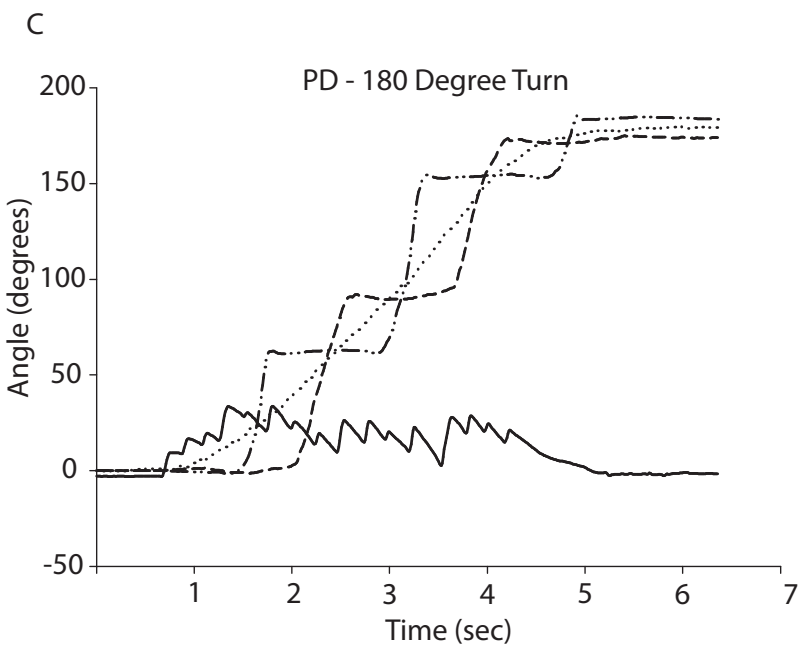
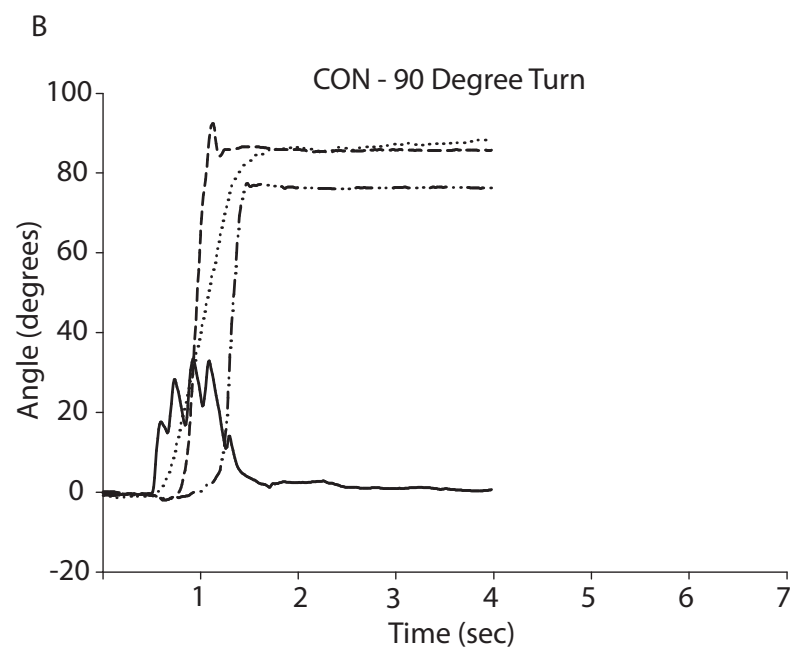
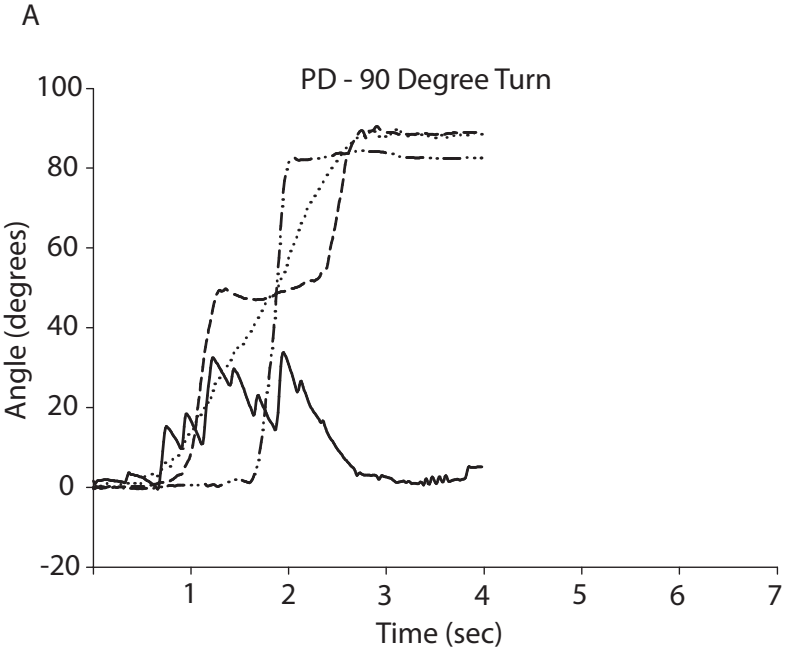
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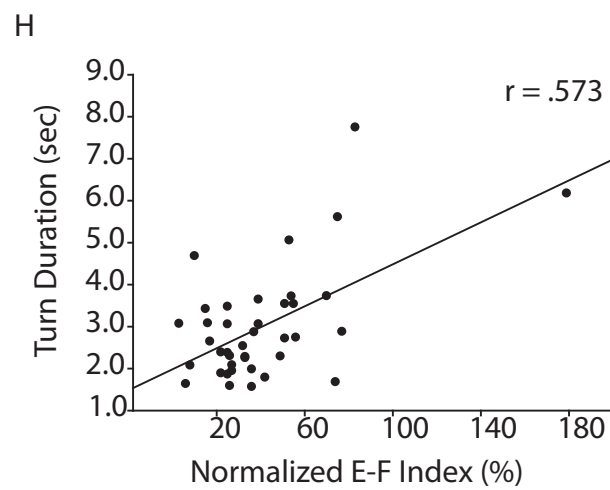
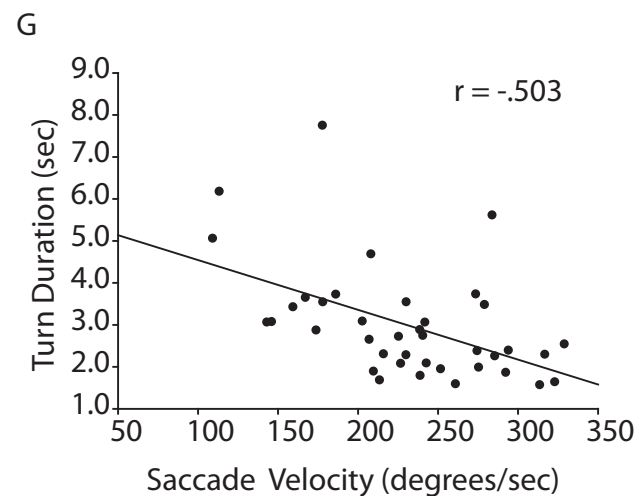
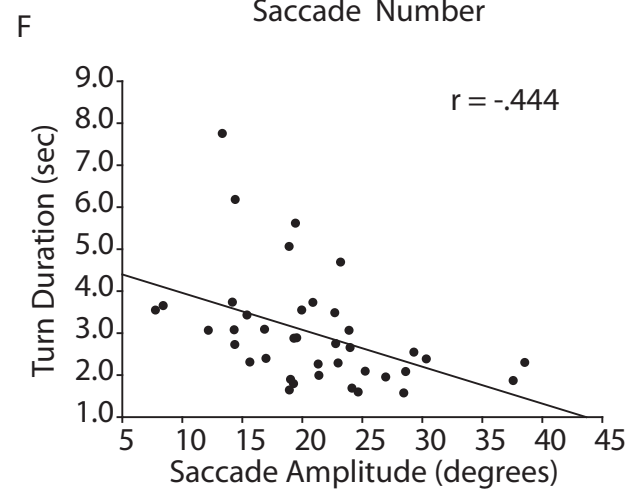
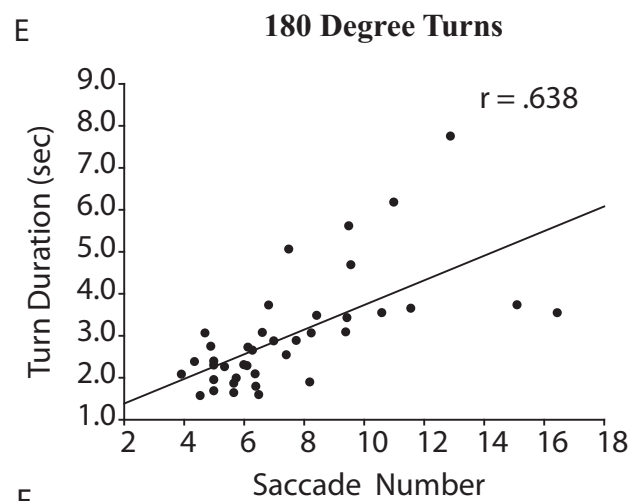
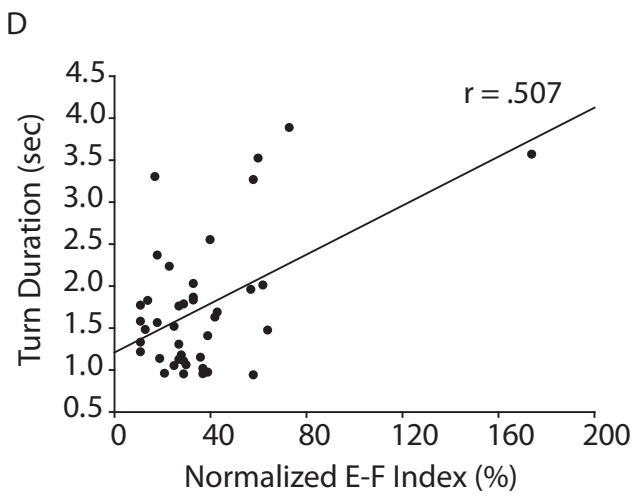
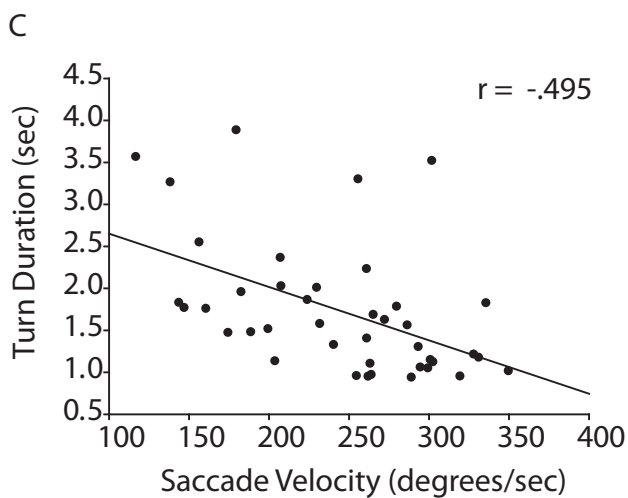
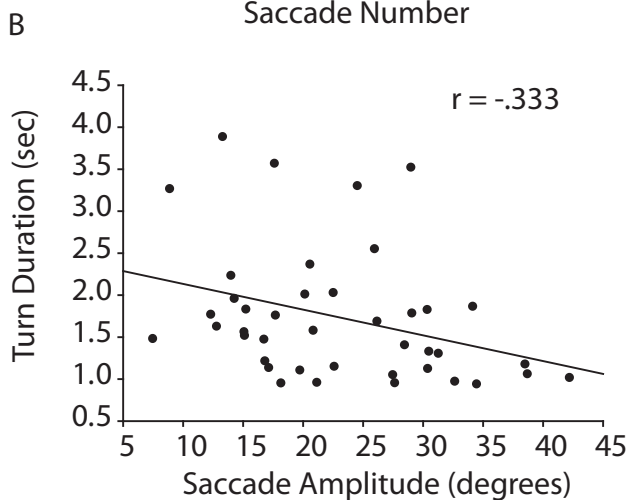
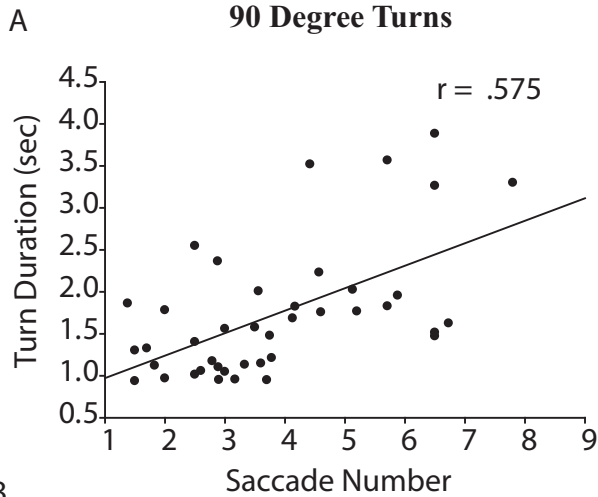
489 **Figure 2. Correlations between turn duration and various parameters of saccade**  
490 **performance.**

491 Correlations include all subjects from both the PD and control groups, with Pearson correlation  
492 coefficients shown in top right of each panel. The left column shows correlations of saccade  
493 number (A), amplitude of the first saccade (B), velocity of the first saccade (C), and normalized  
494 timing of the first saccade relative to the first step (D) for 90 degree turns. The right column (E-  
495 H) shows the same correlations for 180 degree turns.

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**Table 1. Subject Demographics**

	PD (90° turns)	PD (180° turns)	Controls
Age (years)	68.7 ±10.2	68.6 ±10.8	68.8 ± 11.4
Male/Female	14/8	13/7	11/8
<u>PD Characteristics</u>			
Disease Duration (years)	7.4 ± 5.8	6.8 ± 5.6	
Hoehn & Yahr Stage	2.3 ± 0.4	2.3 ± 0.4	
(# in each stage)	Stage 1 = 1	Stage 1 = 1	
	Stage 2 = 9	Stage 2 = 7	
	Stage 2.5 = 10	Stage 2.5 = 10	
	Stage 3 = 2	Stage 3 = 2	
Freezing of Gait Score	5.7 ± 4.8	5.8 ± 5.0	
No. Freezers (FOG 3 ≥ 2)	8	8	
MDS-UPDRS III Score	40.1 ± 11.9	38.7 ± 11.5	

Values are means ± standard deviations.

**Table 2. Turn Performance and Oculomotor Performance During 90 and 180 Degree Turns**

Measure	90° Turns			180° Turns		
	PD		Controls	PD		Controls
# of Steps	4.3 ± 2.6	*	2.7 ± 0.8	7.7 ± 5.1	*	4.5 ± 0.9
Turn Duration (seconds)	2.1 ± 0.8	†	1.4 ± 0.5	3.6 ± 1.5	†	2.4 ± 0.7
# of Saccades	4.5 ± 1.7	†	3.1 ± 1.4	8.9 ± 3.2	†	6.0 ± 1.5
First Saccade Amplitude (degrees)	20.6 ± 8.1		25.7 ± 8.4	17.4 ± 4.6	†	24.7 ± 6.7
First Saccade Velocity (deg/sec)	219.0 ± 65.6	†	273.1 ± 41.1	206.7 ± 61.2	†	255.3 ± 39.5
Norm E-H Index (% of 1 <sup>st</sup> gait cycle)	19.4 ± 19.3		11.5 ± 6.1	26.8 ± 25.0	*	13.4 ± 7.2
Norm E-F Index (% of 1 <sup>st</sup> gait cycle)	45.4 ± 33.9	*	25.4 ± 9.7	52.3 ± 38.1	*	28.1 ± 11.5

Values are means ± standard deviations.

\* Significantly different between groups,  $p < 0.05$

† Significantly different between groups,  $p < 0.01$

**Table 3. Results of Linear Regression Analysis**

		B	SE (B)	$\beta$	p
90° Turns	# Saccades	18.24	6.40	.392	.007
	Saccade Velocity	-.232	.18	-.180	.211
	Norm E-F Index	94.59	36.93	.329	.015
180 ° Turns	# Saccades	18.72	5.79	.407	.003
	Saccade Velocity	-.283	.28	-.248	.048
	Norm E-F Index	147.01	53.01	.337	.009

90° Turns,  $R^2 = .481$

180° Turns,  $R^2 = .578$

**Table 4. Comparison of Freezers and Non-Freezers**

	90° Turns		180° Turns	
	Freezers (n=8)	Non-Freezers (n=14)	Freezers (n=8)	Non-Freezers (n=12)
Disease Duration	8.6 ± 7.0	6.7 ± 5.2	8.3 ± 6.7	5.8 ± 4.8
MDS-UPDRS III Score	40.1 ± 13.1	40.1 ± 11.7	39.9 ± 12.9	37.8 ± 11.0
# Saccades	4.5 ± 2.0	4.6 ± 1.6	9.1 ± 2.6	8.8 ± 3.7
Saccade Amplitude (degrees)	20.6 ± 8.5	20.7 ± 8.2	18.2 ± 3.4	16.9 ± 5.4
Saccade Velocity (deg/sec)	183.8 ± 59.8	239.2 ± 61.7	187.7 ± 61.5	219.4 ± 60.2
Norm E-F Index	61.1 ± 49.0	36.4 ± 18.2	70.8 ± 48.1	40.0 ± 24.8
Total Steps	6.4 ± 3.6 *	3.1 ± 0.5	11.1 ± 6.7 *	5.4 ± 1.1
Turn Duration (seconds)	2.8 ± 8.1 †	1.6 ± 0.4	4.7 ± 1.7 *	2.8 ± .77

Values are means ± standard deviations.

\*Significantly different between groups,  $p < 0.05$

†Significantly different between groups,  $p < 0.05$