Title

Cognitive–Motor Learning in Parkinson's Disease

Journal

Neuropsychology, 11(2)

ISSN

0894-4105

Authors

Haaland, Kathleen Y
Harrington, Deborah L
O'Brien, Shannon
et al.

Publication Date

1997-04-01

DOI

10.1037/0894-4105.11.2.180

Peer reviewed

Neuropsychology
1997, Vol. 11, No. 2, 180–186

Cognitive–Motor Learning in Parkinson's Disease

Kathleen Y. Haaland and Deborah L. Harrington
Veterans Affairs Medical Center and University of New Mexico

Shannon O'Brien
University of New Mexico

Neal Hermanowicz
Glenbrook Hospital

Procedural learning deficits are common in Parkinson's disease (PD), but contradictory results have been reported in rotary pursuit learning. This article compared rotary pursuit learning in 2 nondemented PD groups and 2 normal control (NC) groups, using a between-subjects group design in which 3 rotation speeds were presented either randomly or in blocks. The pattern of learning differed between the randomized and the blocked conditions in the NC, but not in the PD groups. Learning was impaired in the PD group in the random condition only. Memory, visuospatial, or executive skills were not associated with the PD group's poorer learning in the randomized context. Results show that procedural learning deficits are not universal with basal ganglia abnormalities but rather depend on the specific cognitive requirements of the learning context.

Although most studies of Parkinson's disease (PD) have shown that procedural learning is impaired and declarative learning is intact (Harrington, Haaland, Yeo, & Marder, 1990; Saint-Cyr, Taylor, & Lang, 1988), procedural learning deficits have not always been found (Bondi & Kaszniak, 1991; Harrington et al., 1990; Heindel, Salmon, Shults, Walicke, & Butters, 1989). These latter findings raise the possibility that the processing requirements of a procedural learning task are paramount in determining whether the basal ganglia play a crucial role. For example, we (Harrington et al., 1990) reported that PD patients showed deficits in motor learning (rotary pursuit) but not in perceptual learning (mirror reading), which was consistent with the superficial focus of PD as a movement disorder. However, other differences in the cognitive processing requirements of motor and perceptual learning tasks may be as important or more important (Kohlers & Roediger, 1984), especially as motor learning deficits in PD have not always been reported (Bondi & Kaszniak, 1991; Harrington et al., 1990; Heindel et al., 1989).

The present study investigated whether differences in the cognitive requirements of the task could help clarify the discrepant findings that have been reported in rotary pursuit learning studies of PD. Rotary pursuit learning deficits were found in PD patients in one study in which three rotation speeds were randomly presented (Harrington et al., 1990). These results contrasted with two other studies in which normal rotary pursuit learning was found in PD patients when a single rotation speed was used (Bondi & Kaszniak, 1991; Heindel et al., 1989). When participants are required to track a target at different speeds (i.e., revolutions per minute [rpms]) from trial to trial, different motor programs must be developed and retrieved at the beginning of each trial, with the requirement of switching from one program to another on sequential trials. There also may be interference from other motor programs that may remain active in the motor buffer. In contrast, when learning one speed, only a single motor program needs to be developed and accessed at a time. In the blocked condition, programming demands are also likely to be minimal because the motor program may remain active in the motor buffer, so that it only needs to be activated at the beginning of each trial. In fact, memory studies have shown that random presentations of stimulus conditions lead to different patterns of learning and retention than do blocked presentations, which is referred to as the *context interference effect* (Husak, Cohen, & Schandler, 1991; Lee & Magill, 1983; Magill & Hall, 1990; Shea & Morgan, 1979).

Many of the cognitive processes necessary to facilitate learning in the randomized condition are impaired with PD. PD patients have difficulty developing and modifying motor programs for complex movements (Flowers, 1976; Harrington & Haaland, 1991). This deficit is particularly severe if different motor programs must be accessed sequentially or simultaneously (Benecke, Rothwell, Dick, Day, & Marsden, 1986, 1987; Harrington & Haaland, 1991). PD also impairs the ability to maintain motor programs in the face of competing programs and to switch among different motor programs (Harrington & Haaland, 1991; Robertson &

Kathleen Y. Haaland and Deborah L. Harrington, Veterans Affairs Medical Center, Albuquerque, New Mexico, and Neurology, Psychology, and Psychiatry Departments, University of New Mexico; Shannon O'Brien, Psychology Department, University of New Mexico; Neal Hermanowicz, Neurology Department, Glenbrook Hospital, Chicago, Illinois.

This research was supported by a grant from the Department of Veterans Affairs. Parts of this research were reported at the 1995 meeting of the International Neuropsychological Society. We thank Gabrielle Mallory, Rachael Dowler, and Lee Stapp for their research assistance and Lovelace Medical Center for referring their patients.

Correspondence concerning this article should be addressed to Kathleen Y. Haaland, Psychology Service (116B), Veterans Affairs Medical Center, Albuquerque, New Mexico 87108.

Flowers, 1990). These types of cognitive abilities likely impact on the development and modification of action plans during procedural learning, especially when participants are required to alternate among different motor plans, such as when rpm conditions are randomized in rotary pursuit learning. In contrast, PD does not result in an inability to construct, retrieve, and execute a single motor program (Bloxham, Mindel, & Frith, 1984; Harrington & Haaland, 1991; Robertson & Flowers, 1990), which would suggest that the PD group should show no learning deficits when rpm conditions are blocked in rotary pursuit learning.

The present study tested the hypothesis that rotary pursuit learning would be impaired in PD when the rotation speeds were randomized, but not when they were blocked across learning trials. This prediction is consistent with the view that the basal ganglia are involved in the control of some, but not all, forms of procedural learning, even when the two procedural tasks require the same movements.

We also investigated the relationship between executive functions and rotary pursuit learning. Deficits in set maintenance and shifting as well as other executive functions have also been found on nonmotor tasks in patients with PD (Bondi, Kaszniak, Bayles, & Vance, 1993; Flowers & Robertson, 1985; Saint-Cyr et al., 1988), and these deficits have been associated with the preponderance of anatomical connections between the basal ganglia and the prefrontal lobes (Alexander, DeLong, & Strick, 1986). We predicted that executive function deficits in PD would be associated with impaired learning in the randomized condition, whereas other cognitive deficits, such as memory or visuospatial skills, would not be related to rotary pursuit learning.

Method

Participants

A total of 40 PD and 30 normal control (NC) participants were studied. NC and PD participants were excluded for history of psychiatric or neurological problems except for the diagnosis of PD in the PD group. Participants with scores below 24 on the Mini-Mental State exam (Folstein, Folstein, & McHugh, 1975) were excluded for possible dementia. Four PD patients were excluded, one because of dementia, and three others were unable to complete testing because of fatigue. As can be seen in Table 1, the four PD and NC groups were matched in age, gender, education, mental status, and general information (Wechsler Adult Intelligence Scale–Revised [WAIS–R]; Wechsler, 1981).

Table 2
Symptom Severity of Parkinson Groups

Measure	Blocked PD (n = 20)		Random PD (n = 20)	
	M	*SD*	*M*	*SD*
Unified Parkinson's Disease Rating Scale[a]	30.7	19.5	31.3	15.0
Hoehn & Yahr[b]	2.3	1.0	2.6	0.8
Disease duration (years)	6.5	7.0	6.4	4.9

Note. PD = Parkinson's disease.
[a]The total score on the Unified Parkinson's Disease Rating Scale included an assessment in the following areas: (a) mentation, behavior, and mood, (b) activities of daily living, (c) motor examination, and (d) dyskinesias. The maximum score is 136, with higher scores reflecting greater disability. [b]Scores on the Hoehn & Yahr Scale range from 0 to 5.0, with higher scores reflecting greater disability.

Table 2 describes the PD groups' disease duration and symptom severity. A board certified neurologist (N.H.) rated the symptom severity of the PD patients using the Hoehn and Yahr Scale (Hoehn & Yahr, 1967) and the Unified Parkinson's Disease Rating Scale (UPDRS; Fahn et al., 1987). Of the patients, 20% were Stage 1 (unilateral parkinsonian symptoms), 33% were in Stage 2 (bilateral symptoms without balance impairment), 40% were in Stage 3 (bilateral symptoms with some postural instability), and 8% were in Stage 4 (severe disability, but able to walk or stand unassisted). Mean symptom severity ratings from the UPDRS and disease duration were matched between the two PD groups. All of the patients were medicated at the time of testing; 85% were on Selegiline, 73% on L-dopa, 23% on anticholinergic medications, and 10% on Amantadine.

Procedures

Participants performed a rotary pursuit task (Lafayette, Model 30013) at varying target speeds of 15, 45, and 60 rpms. The 15-rpm condition was substituted for the 30-rpm condition used in our previous study to be more comparable with the other studies being contrasted (Bondi & Kaszniak, 1991; Heindel et al., 1989). Participants were randomly assigned to one of two learning contexts, each of which consisted of 90 trials. In the blocked context, participants performed 30 consecutive trials of a particular rpm, switched to 30 trials at another rpm, and then completed 30 more trials at the remaining rpm. The order of the rpm conditions was counterbalanced across participants. In the random learning context, the presentation order of the rpm conditions was pseudo-randomized so that one of each rpm occurred every 3 trials. After

Table 1
Demographic Characteristics and Cognitive Status of Participant Groups

Measure	Blocked PD (n = 20)		Random PD (n = 20)		Blocked NC (n = 15)		Random NC (n = 15)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age	66.6	9.2	67.5	7.7	66.3	7.3	66.7	12.7
Sex (% male)	66.7	0.49	66.7	0.49	66.7	0.49	66.7	0.49
Education	15.8	2.7	14.6	3.3	15.4	3.6	15.4	2.7
Mini-Mental State exam	27.6	2.1	27.5	2.3	28.6	1.5	28.9	1.0
Information (Age scale)	13.0	2.0	11.4	2.9	13.3	2.4	13.3	2.6

Note. PD = Parkinson's disease; NC = normal control.

every 30 trials in both learning contexts, there was a 30-min break that was filled with neuropsychological testing, the test order of which was counterbalanced across participants. The dependent measure in the rotary pursuit task was the mean time on target. The mean of two consecutive trials at the same rpm was used in the data analyses.

Neuropsychological tests of executive functions, memory, attention, and visuospatial skills were administered to all participants. Table 3 lists these tests together with the group means and standard deviations. The tests and corresponding measures of central executive function included (a) the difference between color and color–word conditions on the Stroop test (Stroop, 1935), (b) the ratio of the number of figures drawn in 60 s with and without interference (e.g., draw a circle at the word *cross* vs. draw a circle at the word *circle*) on the Cross–Circle Test (Luria, 1966), (c) the number of categories and perseverative errors on the modified Wisconsin Card Sorting Test (Nelson, 1976; the materials and procedures were followed except that participants were not cued when the sorting principle changed), and (d) the proportion of correct responses on the Luria screening test (Luria, 1966), which examines response inhibition, simultaneous hand alternations, and rhythm sequences. The memory measures were obtained from the modified version of the California Verbal Learning Test (i.e., three trials with no interference list or cued recall; Delis, Kramer, Kaplan, & Ober, 1987) and consisted of the total number of items recalled across three trials and the percentage of items that were forgotten on delayed recall (e.g., [Trial 3 recall − delayed recall]/Trial 3 recall). The total raw score on the WAIS–R Digit Span (Wechsler, 1981) was used as the measure of attention, and the raw score from the Judgment of Line Orientation (Benton, Hamsher, Varney, & Spreen, 1983) Test was the measure of visuospatial skills.

All of the measures from the neuropsychological tests were transformed into z scores using the means and standard deviations from the NC group. Two composites were then computed for the areas of central executive function and memory by summing the z scores that composed each composite and computing the mean. The z scores from the Digit Span and Judgment of Line Orientation tests were used as the measures of attention and visuospatial skills.

Table 4
Means and Standard Deviations of Standardized Composite Scores

Measure	Blocked PD	Random PD	Blocked NC	Random NC
n	20	20	15	15
Executive function				
M	−0.20	−0.43	0.00	0.01
SD	0.73	0.95	0.49	0.49
Memory				
M	−1.16	−0.78	−0.07	0.08
SD	1.51	0.98	0.67	0.80
Attention				
M	−0.34	−0.18	−0.16	0.16
SD	0.83	1.28	0.81	1.17
Visuospatial				
M	−0.49	−1.37	−0.25	0.25
SD	1.58	1.60	1.02	0.94

Note. PD = Parkinson's disease; NC = normal control participant.

The z scores for these four measures can be seen in Table 4. An analysis of variance (ANOVA) with group (PD, NC) and learning context (random, blocked) as the between-subject variables showed that memory, $F(1, 66) = 13.87$, $MSE = 1.16$, $p < .001$, and visuospatial skills, $F(1, 66) = 7.93$, $MSE = 1.87$, $p < .01$, were diminished in the PD groups relative to the control groups. There also was an interaction of Group × Context, $F(1, 66) = 4.36$, $MSE = 1.87$, $p < .05$, for visuospatial skills. Follow-up analyses showed that visuospatial skills were impaired only in the random PD group in comparison to the random NC group, $F(1, 33) = 12.16$, $MSE = 1.86$, $p < .01$. Although attention was normal in the PD groups, there was a trend for decreased executive functioning in both PD groups, $F(1, 66) = 3.38$, $MSE = 1.47$, $p = .07$. These findings indicated that there was some evidence of mild cognitive decline in the PD groups in memory, visuospatial, and executive functions. Thus, the statistical analyses examined the relationship of each of these areas to rotary pursuit learning.

Table 3
Means and Standard Deviations of Raw Scores on Neuropsychological Tests

	Blocked PD (n = 20)		Random PD (n = 20)		Blocked NC (n = 15)		Random NC (n = 15)	
Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Executive function								
Stroop[a]	23.15	9.58	24.11	9.74	29.00	8.12	23.40	5.85
Cross–Circle Ratio[b]	.66	.14	.67	.20	.69	.10	.69	.12
WCST Categories[c]	4.40	1.90	4.00	1.78	5.00	1.60	4.73	1.58
WCST Perseverative[c]	6.00	8.71	7.10	7.80	3.30	4.5	3.00	4.0
Luria Screen[d]	.89	.10	.81	.22	.95	.05	.87	.18
Memory[e]								
Sum of recall	19.05	7.17	20.60	6.41	26.40	5.70	26.93	3.7
Percentage lost	.15	.33	.08	.20	.05	.12	.01	.21
Attention[f]								
Digit Span	13.85	3.00	14.45	4.64	14.53	2.95	15.67	4.24
Visuospatial[g]								
Line Orientation	24.05	5.41	21.05	5.48	24.90	3.5	26.60	3.2

Note. PD = Parkinson's disease; NC = normal control participant.
[a]The difference between color and color–word (Stroop, 1935). [b]The ratio of the number of figures drawn in 60 s with and without interference (Luria, 1966). [c]The number of categories and perseverative errors on the modified Wisconsin Card Sorting Test (WCST; Nelson, 1976). [d]The proportion correct (Luria, 1966). [e]Scores are from the California Verbal Learning Test (Delis et al., 1987) and reflect the total recall across three trials and the percentage of items forgotten on delayed recall. [f]The total raw score on the Wechsler Adult Intelligence Test—Revised Digit Span (Wechsler, 1981). [g]The raw score from Judgment of Line Orientation (Benton et al., 1983).

Results

An initial analysis examined performance in the NC groups to determine if there was a context learning effect. Although the context effect did not reach significance, there was a significant Context × Rpm interaction, F (2, 56) = 9.38, MSE = 122.2, $p < .001$, which was due to a tendency for better performance (i.e., more time on target) in the blocked than in the random condition, but only for the 15-rpm condition (M = 14.6, SD = 0.6 and M = 16.2, SD = 0.5) for the randomized and blocked conditions, respectively, $F(1, 28) = 3.96$, $MSE = 270.6$, $p = .056$. There also was a significant Context × Trial interaction, $F(14, 392) = 6.86$, $MSE = 8.1$, $p < .001$, which was due to a difference in the pattern of learning between the random and blocked conditions. Figure 1 shows that performance in the blocked condition reached asymptote more rapidly than in the random condition, particularly for the 15-rpm condition. Despite this finding, there was no significant difference in time on target between the NC groups in the random and blocked conditions at the first or the last trial. The condition and Condition × Trial × Rpm interactions were not significant. These results are consistent with other studies (Husak et al., 1991; Lee & Magill, 1983; Shea & Morgan, 1979) and suggest that in normal groups the processes involved in learning were different during the randomized and blocked conditions.

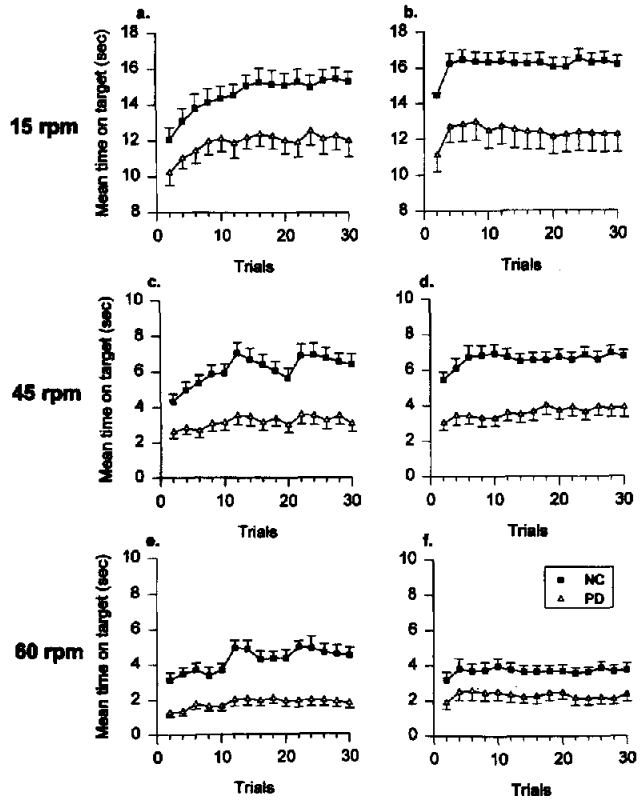

Figure 1. Rotary pursuit learning for the Parkinson's disease (PD) and normal control (NC) groups at 15, 45, and 60 rpm, separately graphed for the random (a, c, e) and blocked (b, d, e) conditions. Error bars represent the standard errors of the mean.

Before proceeding with an analysis of learning in the PD group, it was critical to ensure that performance levels on Trial 1 did not differ between the PD and NC groups. In our previous study (Harrington et al., 1990), we examined learning in PD as a function of target speed because the initial performance levels did not differ between the PD and control groups in any of the three rpm conditions of the rotary pursuit task. In the present study, time on target in the first trial was lower in the PD groups than in the NC groups, $F(1, 66) = 20.39$, $MSE = 10.90$, $p < .001$. However, group did not interact with condition or rpm, indicating that this group difference on Trial 1 was the same, regardless of the target speed and the learning context. Separate analyses for each rpm further substantiated this finding by showing that the PD group performed worse than the control group on Trial 1, $F(1, 68) = 10.09$, $MSE = 11.36$, $p < .01$; $F(1, 68) = 23.69$, $MSE = 3.11$, $p < .001$; and $F(1, 68) = 19.25$, $MSE = 2.22$, $p < .001$, for the 15-, 45-, and 60-rpm conditions, respectively.

In the remaining analyses, we equated the initial performance level of the groups by examining learning in the 45-rpm condition for the PD groups and in the 60-rpm condition for the NC groups. There were no group differences at Trial 1 in these rpm conditions, $F(1, 66) < 1$. Moreover, there was not a reliable difference at Trial 1 between the two learning contexts, $F(1, 66) < 1$, or a Group × Learning Context interaction, $F(1, 66) < 1$. These findings confirmed that the initial performance level was equated among all four groups using these rpm conditions. A mixed-model ANOVA with repeated measures then was used to test the between-subject effects of learning context (blocked, random) and group (PD, NC) and the within-subject effect of trial (Trial 1 to Trial 15). The linear and quadratic trends of trial were analyzed because a preliminary inspection of the data showed that these trends best characterized the learning curves of all groups. Most of the interactions involving a between-subject factor with trial were due to the linear effects of trial. Thus, unless otherwise specified, all of the interactions with trial can be assumed to involve the linear trend. The quadratic trends of trial are discussed only when significant effects (e.g., $p < .05$) were obtained.

The linear, $F(1, 66) = 21.27$, $MSE = 2.43$, $p < .001$, and quadratic trends of trial, $F(1, 66) = 14.98$, $MSE = 1.03$, $p <$

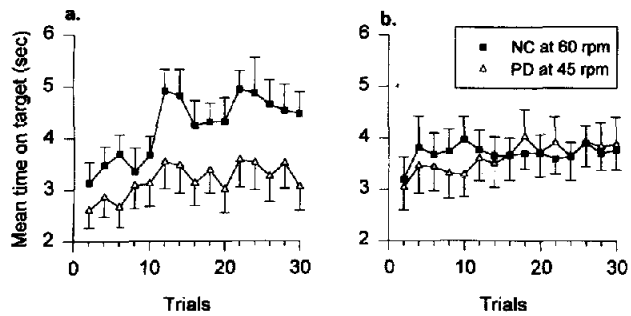

Figure 2. Rotary pursuit learning at 45 (rpm) for the Parkinson's disease (PD) group and at 60 rpm for the normal control (NC) group separately graphed for the random (a) and blocked (b) conditions. Error bars represent the standard error of the means.

.001, can be seen in Figures 2a and 2b. The quadratic trend shows that, in general, time on target improved up to about Trial 5 or 6, after which an asymptote was reached. Figure 2 also suggests that the pattern of learning differed between the PD and NC groups, primarily in the randomized condition. This observation was confirmed by the Group × Context × Trial interaction, $F(1, 66) = 5.12$, $MSE = 2.43$, $p < .05$. In follow-up analyses of this interaction, context interacted with trial in the NC groups, $F(1, 28) = 7.33$, $MSE = 2.52$, $p < .025$, but not in the PD groups, $F(1, 28) < 1$. Figures 2a and 2b show that the former effect was due largely to a faster rate of learning in the random NC group than in the blocked NC group. By comparison, the learning rates in the random and blocked PD groups were very similar.

Additional follow-up analyses revealed a trend for a Group × Trial interaction in the randomized, $F(1, 33) = 4.04$, $MSE = 2.14$, $p = .053$, but not the blocked learning context. Figure 2a shows that the former effect was due to faster learning rates in the random NC group than in the random PD group. Although both groups showed learning in the random condition, $F(1, 14) = 24.32$, $MSE = 1.84$, $p < .001$, and $F(1, 19) = 4.43$, $MSE = 2.37$, $p < .05$, for the linear trend of trial in the NC and PD groups, respectively, and $F(1, 14) = 16.41$, $MSE = .77$, $p < .01$, and $F(1, 19) = 6.51$, $MSE = 1.08$, $p < .05$, for the quadratic trend of trial in the NC and PD groups, respectively, by the last two trials, the random NC group spent more time on target than the random PD group, $F(1, 33) = 5.15$, $MSE = 3.40$, $p < .05$. These findings contrasted with those from the blocked learning context in which the PD and NC groups showed similar learning rates.

Disease Duration and Severity

To determine whether disease duration or symptom severity affected rotary pursuit learning, three separate classical regression analyses were conducted using the linear trend of trial in the 45-rpm condition as the dependent measure. The independent variables in each analysis included the symptom rating scales (UPDRS and the Hoehn & Yahr Scale) or disease duration and the first- through the third-order interactions of these variables with trial and learning context were tested. Disease duration was not related to mean time on target (i.e., average of Trials 1–30), learning rate, or the amount of learning as a function of context. Both the UPDRS and the Hoehn and Yahr Scale were negatively correlated with mean time on target, $F(1, 34) = 34.18$, $MSE = 30.35$, $p < .001$, $r = -.69$, and $F(1, 34) = 28.67$, $MSE = 33.35$, $p < .001$, $r = -.68$, respectively, indicating that individuals with more severe symptoms showed less time on target across all trials. However, neither of the disease severity measures correlated with rotary pursuit learning rates or the amount of learning as a function of context. Thus, disease severity and duration could not explain any of the variability in learning rates within the random or the blocked PD groups.

Neuropsychological Functioning

Recall that the PD group showed significantly lower memory and visuospatial performance, and there was a trend for somewhat lower central executive functioning as well. To determine if these cognitive factors could explain the depressed rotary pursuit learning rates in the random PD group, we performed three separate classical regression analyses in which the dependent measure was the linear trend of trial at the 45 rpm for the PD groups and the 60 rpm for the NC groups. The independent variables in each analysis included the z score from the executive function and memory composites and the z score from the Judgment of Line Orientation Test. In addition, we tested the first- through the fourth-order interactions of these variables with group, trial, and learning context.

Memory abilities were not related to the mean rotary pursuit performance level (i.e., the average time on target of Trials 1–30). Most important, there were no interactions of memory ability with group, trial, or the learning context. By contrast, both executive function and visuospatial abilities were positively related to the mean rotary pursuit performance level, $F(1, 65) = 9.70$, $MSE = 36.68$, $p < .01$, $r = .48$, and $F(1, 65) = 38.19$, $MSE = 25.10$, $p < .01$, $r = .68$, respectively, so that individuals with poorer skills in these areas tended to show less time on target across all trials. However, there were no interactions of executive function or visuospatial skills with group, trial, or the learning context. These findings demonstrated that cognitive functioning in these areas could not explain the depressed learning rate in the random PD group.

Discussion

Influence of Context on Procedural Learning in the NC Group

Results in the NC group are critical to demonstrate the influence of different cognitive factors on learning in different contexts. Our finding of a slower learning rate in the NC group for the randomized than the blocked context is consistent with other findings pertaining to the context interference effect (Husak et al., 1991; Lee & Magill, 1983; Magill & Hall, 1990; Shea & Morgan, 1979). Maximal performance was reached more rapidly for the blocked condition, and Figure 1 demonstrates that these effects were more marked in the 15-rpm condition, although there was not a significant Context × Rpm × Trial interaction for the NC group. These results suggest that the cognitive requirements of the randomized context differ from the blocked context, which is consistent with many studies in normal participants (Magill & Hall, 1990), although there have been only a few investigations of this issue using rotary pursuit learning (Heitman & Gilley, 1989; Whitehurst & Del Rey, 1983). The randomization of learning contexts presumably requires successive reconstruction of different motor programs for each rpm, and greater experience reconstructing those programs is thought to improve the quality and retrievability of the programs. Some of these processes are likely to produce interference in early stages of learning,

which accounts for the slower learning in the randomized context in the NC group. However, our data suggest that at faster speeds (60-rpm condition) some of these processes might in fact facilitate learning, although this possibility has not been previously studied.

Procedural Learning Deficits in Parkinson's Disease

Our data showed that in the blocked condition, the PD group's pattern of learning and ultimate performance level was not impaired, consistent with previous studies of rotary pursuit learning in PD (Bondi & Kaszniak, 1991; Heindel et al., 1989). This suggests that PD patients can develop a single motor program, perfect that program, and use it as effectively as can the NC group. This is consistent with other data in which PD patients showed a normal ability to use predictable information to improve tracking performance (Bloxham et al., 1984), to preprogram sequences of repetitive hand postures (Harrington & Haaland, 1991), and to learn a single sequence presented repeatedly on successive trials (Robertson & Flowers, 1990). Hence, basal ganglia abnormalities do not entirely disrupt skill learning.

In contrast, in the randomized condition, the rate of learning was slower for the PD than the control groups, perhaps because of the interference among competing motor programs or problems in constructing and switching among multiple motor programs (Benecke et al., 1986, 1987; Harrington & Haaland, 1991; Robertson & Flowers, 1990). Although the current experiment cannot differentiate among these processing explanations, it is consistent with the deficits in PD in planning and executing sequences that contain different hand postures, which are dependent on multiple motor programs (Harrington & Haaland, 1991). Specifically, PD patients showed little or no evidence of preprogramming all of the movements contained within heterogenous sequences, and their resultant performance was slower and less accurate than that of NC participants, but largely when switching among different hand postures. These results suggested that PD produces deficits in planning and executing sequences that require the construction of multiple action plans and switching among different motor programs. Others have suggested that PD impairs the maintenance of one plan of action against competing alternatives (Robertson & Flowers, 1990), which also could explain the PD group's learning impairment in the randomized condition. However, an impairment in PD in the acquisition of motor set (Frith, Bloxham, & Carpenter, 1986) does not appear to explain the procedural learning deficits demonstrated in this study, because this explanation would predict impaired learning in the blocked condition, which was not found.

Relationship of Context Learning Deficits and Cognitive Functioning

The ability to preplan, maintain set, and switch among several alternatives are abilities that are not specific to the motor system. Other studies have demonstrated that PD produces deficits in set shifting or set maintenance in nonmotor tasks as well (Flowers & Robertson, 1985; Owen et al., 1992; Richards, Cote, & Stern, 1993). In addition, PD produces a variety of other executive function deficits, including difficulty generating solutions efficiently in problem solving tasks (Owen et al., 1992; Richards, Cote, & Stern, 1993), rapidly initiating unique verbal or nonverbal responses (Bondi, Kaszniak, Bayles, & Vance, 1993), and poorer working memory (Owen et al., 1992). These deficits have been associated with diminished functioning of the frontal lobes or their interconnections, or both (Alexander et al., 1986; Antonini et al., 1995; Saint-Cyr et al., 1988). We predicted that some or all of these skills would be required for successful learning in the randomized but not in the blocked condition of the rotary pursuit task. Contrary to this hypothesis, executive functioning and visuospatial abilities were not associated with learning in either context, although they were correlated with less time on target in both learning conditions.

This finding indicates that executive function deficits on nonmotor tasks cannot explain the PD group's impaired learning, but this conclusion may be due to characteristics of our parkinsonian sample and the sensitivity of the executive function measures used. Our PD sample showed only a trend for diminished executive functioning, and their performance levels as a group on most neuropsychological tests were within normal limits. Others have also reported normal executive functioning in PD using the Wisconsin Card Sorting Test (Canavan et al., 1989), likely because PD patients are a heterogenous group, many of whom show little or no evidence of cognitive impairment on neuropsychological testing. Hence, the restricted range of performance on the executive function composite in our study would limit the likelihood of obtaining a statistically significant relationship. In addition, although the tests we used are thought to be sensitive to set maintenance (e.g., Wisconsin Card Sort; Luria Screen), set switching (e.g., Wisconsin Card Sorting Test, Cross–Circle Test), and ability to inhibit inappropriate responses (e.g., Wisconsin Card Sorting Test, Stroop test), there is no emphasis placed on the speed of these operations, which is critical in the rotary pursuit learning task. Switching and planning deficits in PD have been more consistently shown in reaction-time studies examining the planning and execution of responses that are carried out rapidly in time (Harrington & Haaland, 1991; Robertson & Flowers, 1990).

Summary Remarks

Our study confirms the notion that the basal ganglia and its interconnections affect some but not all procedural tasks. Within the same procedural task, deficits can be seen in one condition, but not in another, when the two conditions differ in the cognitive processes required for optimal performance. Clearly, the basal ganglia and its interconnections are not crucial for all forms of procedural learning, but they are essential for sustaining some types of cognitive operations, which are important for some procedural tasks. Although the present study did not test among the various competing cognitive explanations, it is clear that a promising avenue for specifying the bases of procedural learning deficits due to

basal ganglia abnormalities will be to study the cognitive operations engaged by the various procedural paradigms.

References

Alexander, G. A., DeLong, M. R., & Strick, P. L. (1986). Parallel organization of functionally segregated circuits linking basal ganglia and cortex. In W. M. Cowan (Ed.), *Annual review of neuroscience.* (Vol. 9, pp. 357–381). Washington, DC: Society for Neuroscience.

Antonini, A., Vontobel, P., Psylla, M., Gunther, I., Maguire, P. R., Missimer, J., & Leenders, K. L. (1995). Complementary positron emission tomographic studies of the striatal dopaminergic system in Parkinson's Disease. *Archives of Neurology, 52,* 1183–1190.

Benecke, R., Rothwell, J. C., Dick, J. P. R., Day, B. L., & Marsden, C. D. (1986). Performance of simultaneous movements in patients with Parkinson's disease. *Brain, 109,* 739–757.

Benecke, R., Rothwell, J. C., Dick, J. P. R., Day, B. L., & Marsden, C. D. (1987). Disturbance of sequential movements in patients with Parkinson's disease. *Brain, 110,* 361–379.

Benton, A. L., Hamsher, K., Varney, N. R., & Spreen, O. (1983). *Contributions to neuropsychological assessment: A clinical manual.* New York: Oxford University Press.

Bloxham, C. A., Mindel, T. A., & Frith, C. D. (1984). Initiation and execution of predictable and unpredictable movements in Parkinson's Disease. *Brain, 107,* 371–384.

Bondi, M. W., & Kaszniak, A. W. (1991). Implicit and explicit memory in Alzheimer's disease and Parkinson's disease. *Journal of Clinical and Experimental Neuropsychology, 13,* 339–358.

Bondi, M. W., Kaszniak, A. W., Bayles, K., & Vance, K. T. (1993). The contributions of frontal system dysfunction to memory and perceptual abilities in Parkinson's disease. *Neuropsychology, 7,* 89–102.

Canavan, A. G. M., Passingham, R. E., Marsden, C. D., Quinn, N., Wyke, M., & Polkay, C. E. (1989). The performance on learning tasks of patients in the early stages of Parkinson's disease. *Neuropsychologia, 27,* 141–156.

Delis, D. C., Kramer, J. H., Kaplan, E., & Ober, B. A. (1987). *The California Verbal Learning Test—Research edition.* New York: Psychological Corporation.

Fahn, S., Elton, R. L., and members of the UPDRS Development Committee (1987). *The United Parkinson's Disease Rating Scale.* In S. Fahn, C. D. Marsden, D. B. Calne, & M. Goldstein, (Eds.), *Recent developments in Parkinson's disease* (Vol. 2, pp. 153–163). Florham Park, NJ: Macmillan Health Care Information.

Flowers, K. A. (1976). Visual "closed-loop" and "open-loop" characteristics of voluntary movement in patients with Parkinsonism and intention tremor. *Brain, 99,* 269–310.

Flowers, K. A., & Robertson, C. (1985). The effect of Parkinson's disease on the ability to maintain a mental set. *Journal of Neurology, Neurosurgery, and Psychiatry, 48,* 517–529.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-Mental State": A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12,* 189–198.

Frith, C. D., Bloxham, C. A., & Carpenter, K. N. (1986). Impairments in the learning and performance of a new manual skill in patients with Parkinson's disease. *Journal of Neurology, Neurosurgery, and Psychiatry, 49,* 661–668.

Harrington, D. L., & Haaland, K. Y. (1991). Sequencing in Parkinson's disease: Abnormalities in programming and controlling movement. *Brain, 114,* 99–115.

Harrington, D. L., Haaland, K. Y., Yeo, R. A., & Marder, E. (1990). Procedural memory in Parkinson's disease: Impaired motor but not visuoperceptual learning. *Journal of Clinical and Experimental Neuropsychology, 12,* 323–339.

Heindel, W. C., Salmon, D. P., Shults, C. W., Walicke, P. A., & Butters, N. (1989). Neuropsychological evidence for multiple implicit memory systems: A comparison of Alzheimer's, Huntington's, and Parkinson's disease patients. *Journal of Neuroscience, 9,* 582–587.

Heitman, R. J., & Gilley, W. F. (1989). Effects of blocked versus random practice by mentally retarded subjects on learning a novel skill. *Perceptual and Motor Skills, 69,* 443–447.

Hoehn, M. M., & Yahr, M. D. (1967). Parkinsonism: Onset, progression, and morality. *Neurology, 17,* 427–442.

Husak, W. S., Cohen, M. J., & Schandler, S. L. (1991). Activation peaking during the acquisition of a motor task under high and low contextual-interference conditions. *Perceptual and Motor Skills, 72,* 1075–1088.

Kohlers, P. A., & Roediger, H. L. (1984). Procedures of mind. *Journal of Verbal Learning and Verbal Behavior, 23,* 425–449.

Lee, T., & Magill, R. (1983). The locus of contextual interference in motor-skill acquisition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9,* 730–746.

Luria, A. R. (1966). *Higher cortical functions in man.* New York: Basic Books.

Magill, R. A., & Hall, K. G. (1990). A review of the contextual interference effect in motor skill acquisition. *Human Movement Science, 9,* 241–289.

Nelson, H. E. (1976). A modified card sorting test sensitive to frontal lobe defects. *Cortex, 12,* 313–324.

Owen, A. M., James, M., Leigh, P. N., Summers, B. A., Marsden, C. D., Quinn, N. P., Lange, K. W., & Robbins, T. W. (1992). Fronto-striatal cognitive deficits at different stages of Parkinson's disease. *Brain, 115,* 1727–1751.

Richards, M., Cote, L. F., & Stern, Y. (1993). Executive function in Parkinson's disease: Set-shifting or set-maintenance? *Journal of Clinical and Experimental Neuropsychology, 15,* 266–279.

Robertson, C., & Flowers, K. A. (1990). Motor set in Parkinson's disease. *Journal of Neurology, Neurosurgery, and Psychiatry, 53,* 583–592.

Saint Cyr, J. A., Taylor, A. E., & Lang, A. E. (1988). Procedural learning and neostriatal dysfunction in man. *Brain, 111,* 941–959.

Shea, J., & Morgan, R. L. (1979). Contextual interference effects on the acquisition, retention, and transfer of a motor skill. *Journal of Experimental Psychology: Human Learning and Memory, 5,* 179–187.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18,* 643–662.

Wechsler, D. (1981). *Wechsler Adult Intelligence Scale–Revised.* New York: Psychological Corporation.

Whitehurst, M., & Del Rey, P. (1983). Effects of contextual interference, task difficulty, and levels of processing on pursuit tracking. *Perceptual and Motor Skills, 57,* 619–628.

Received April 16, 1996
Revision received August 28, 1996
Accepted September 6, 1996 ■