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MOTOR MEMORY AND THE PRESELECTION EFFECT IN HUNTINGTON'S AND PARKINSON'S DISEASE

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Abstract—Patients with Huntington's disease (HD) and Parkinson's disease (PD) show different patterns of preserved and impaired memory performance. This study investigates explicit memory for movements in HD and PD with a linear positioning apparatus using DICK *et al.*'s procedure (*J. Gerontol.* **43**, 127–135, 1988). In the first experiment, 12 HD patients were compared to 12 matched-controls. HD patients were more impaired than the controls by the delay between criterion and recall movements, whether the delay was filled or unfilled. Switching the limb between criterion and recall movements did not lead to more effects in HD patients and in controls. In the second experiment, 12 non-demented PD patients were compared to matched-controls. PD patients were more impaired than controls when the recall movement was executed with the contralateral hand, but were not more affected by the delay. In both experiments, HD and PD patients, as well as the controls, recalled self-generated preselected movements better than imposed movements. These results suggest the existence of distinct forms of motor memory impairment in some subcortical neurodegenerative diseases.

INTRODUCTION

VERY few experiments have been conducted to explore memory for movements in neurodegenerative diseases. DICK *et al.* [13] compared the performance of DAT patients and control subjects on the recall of discrete motor movements made on a linear positioning apparatus. The DAT patients committed significantly larger reproduction errors than control subjects. The error increased with the delay more in DAT patients than in control subjects. Nevertheless, in both groups subject-generated (preselected) movements were recalled more accurately than experimenter-defined (constrained) movements. This preselection advantage was replicated with a new group of DAT patients, when recall was performed under both same- and switch-limb conditions. These results suggest that DAT patients are deficient at encoding motor information and, once coded, this information is rapidly lost from their short-term memory. Nevertheless, the results also indicate that DAT patients are able to code the meaningful aspect of movements and that, under certain circumstances, their encoding can be facilitated.

The purpose of this exploratory study was to investigate explicit memory for movements in HD patients (Experiment 1) and PD patients (Experiment 2) compared to controls, using the DICK *et al.* procedure [13].

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Many studies have shown that patients with dementia of the Alzheimer type (DAT), Huntington's disease (HD) and Parkinson's disease (PD) display different patterns of preserved and impaired memory performance [5, 6, 8, 20, 33, 45]. In short-term memory, as assessed by digit and block span, DAT and HD patients are usually impaired, while PD patients may be normal. The performance on the Brown–Peterson task is impaired in HD, DAT and demented-PD patients but not in non-demented PD patients [5]. In long-term memory, although DAT and HD patients display similar level of short-delay recall, HD patients show superior verbal recognition, slower forgetting rate, and a lower number of intrusions and false recognitions than DAT patients [12, 42, 45]. Recognition is also more preserved in PD than in DAT [6, 9, 45]. DAT patients are more impaired in tests which depend upon the integrity of semantic knowledge compared to HD patients whose poor performance in episodic and semantic memory tasks has been associated with a general retrieval deficit [27]. Both PD and HD patients have mildly deficient encoding, intact storage and marked difficulty in initiating systematic retrieval strategies but HD patients have a greater free recall impairment, a deficient rate of improvement across learning trials, increased perseveration rate, reduced primacy effect and disproportionate improvement on recognition testing [38].

Differences in implicit memory between DAT, PD and HD patients are also reported [23, 53]. A double dissociation was observed in DAT and HD [8, 50]: most often lexical, semantic priming [23, 48, 50] and pictorial priming [24] were impaired in DAT but not in HD patients, whereas HD patients were impaired on motor skill learning (i.e. pursuit motor) which is preserved in DAT patients [22, 23]. For PD patients, the experimental results concerning motor skill learning are controversial. According to Heindel *et al.* [23], mildly demented PD patients are as severely impaired as HD patients on a pursuit motor learning task, while non-demented PD patients showed normal results [6, 23]. By contrast, Harrington *et al.* [21] found impairments in pursuit motor learning in PD patients which were correlated with the severity of bradykinesia but not with the presence of dementia. Finally, Beatty [5] observed normal pursuit motor learning in non-demented and in mildly demented PD patients. In the mirror reading task, non-demented PD patients displayed comparable accuracy and improvement to control subjects [6] while HD patients were clearly more impaired than PD patients [53]. A double dissociation was observed in DAT and PD patients in the fragmented pictures test [6]: skill learning was impaired in PD patients compared to control subjects and DAT patients, whereas DAT patients were impaired in perceptual memory compared to control subjects and PD patients. Again DAT patients were impaired in word-stem completion priming whereas PD patients did not differ significantly from controls subjects on this task [6]. In the same vein, Heindel *et al.* [25] demonstrated that DAT patients were normally biased by prior exposure to relatively heavy, or light weights in a weight judgement task. In contrast, the weight judgements of HD patients were not significantly influenced by prior experience. In perceptuo-motor adaptation tasks, such as wearing prisms, PD patients have been found inconsistently impaired as compared to normal controls [10, 55, 62]. HD patients failed to adapt to the prisms when provided with visual feedback and showed negative after-effects when the prisms were removed. Their adaptation was significantly correlated to dementia [44]. On the contrary DAT patients displayed normal adaptation to distorting prisms. PD and HD patients have been compared on procedural learning (as assessed with the tower of Toronto task) and declarative memory [47], and heterogeneous patterns have been found within the HD group: some HD patients were comparable to the PD patients (impaired procedural

learning and spared recall and recognition tests) and others were comparable to amnesic patients showing a double dissociation (impaired recall and recognition tests and intact procedural learning).

Given these dissociations in preserved and impaired performances involving various memory processes observed in neurodegenerative diseases, it would not be surprising to find some differences in the motor memory abilities of PD and HD patients, especially as different patterns of subcortical neuropathology and neurotransmitter deficits are caused by the two diseases [38].

According to DICK [14], a distinction has to be made between memory for motors skills and memory for movements. Motor skills are acquired slowly through repeated practice; their learning does not need a conscious recollection of the previous learning episodes and is demonstrated indirectly (implicitly) via improvement in performance. On the contrary, memory for movements involves the explicit (direct) reproduction of the previously learned movements.

METHOD

Subjects

Twelve right-handed out-patients suffering from Huntington's disease, eight women and four men, took part in the study. Diagnosis was established on the basis of neurological signs, family history (at least two known generations) and the natural history of the disorder [18]. Criteria for diagnosis included the presence of chorea, dystonia, rigidity and akinesia or the gradually progressive characteristic disorder of movement, not present at birth, and of insidious onset. Informed consent was obtained from all patients. The patient's age at onset of the first manifestations, duration of illness at the time of entry into the study, years of education, occupation, sex of the parent from whom the disease was inherited, and medications were recorded. Overall functional disability in all subjects was assessed according to SHOULSON and FAHN's [51] staging system in which individuals at stage 1 can lead a normal life, while at stage 5 they require total institutional care. Functional stage [51] was 2 in most of the cases (nine patients): they could manage in daily life without help. One subject had the predominantly rigid form of the disease. Three patients received small doses of haloperidol (3 mg a day) and six received bromocriptine (7.5–10 mg a day) [36]. An estimate of the degree of dementia was obtained with the Mini-Mental State Examination (MMSE, [17]). The patients' scores ranged between 19 and 30 ($M = 24.6 - S.D. = 3.8$). The clinical characteristics of the patients are summarized in Table 1.

Twelve right-handed control subjects were matched for sex, age and educational level with the HD patients. All of them scored at least 29 in the MMSE. They carried out the motor memory task in the same conditions as the patients.

Table 1. Clinical characteristics of Huntington's disease patients

	Sex	Age (years) at test	Age (years) at onset	Duration	Stage	Movements	Transmission	Level of education
1.	M	52	50	3	II	Choreic	M	2
2.	M	54	48	6	III	Choreic	M	1
3.	W	41	39	2	II	Choreic	P	2
4.	M	25	21	4	IV	Rigid form	P	1
5.	W	36	35	1	II	Choreic	P	1
6.	W	39	38	1	II	Choreic	P	1
7.	W	33	27	6	II	Choreic	P	1
8.	W	55	51	4	II	Choreic	M	3
9.	M	31	28	3	II	Choreic	P	2
10.	W	42	40	2	I	Choreic	M	1
11.	W	57	55	2	II	Chor.ath	P	1
12.	W	56	49	7	II	Choreic	M	1

Ath = athetosic; P = paternal transmission; M = maternal transmission; level of education 1 = less than 8 years, 2 = between 8 and 12 years, 3 = more than 12 years of education.

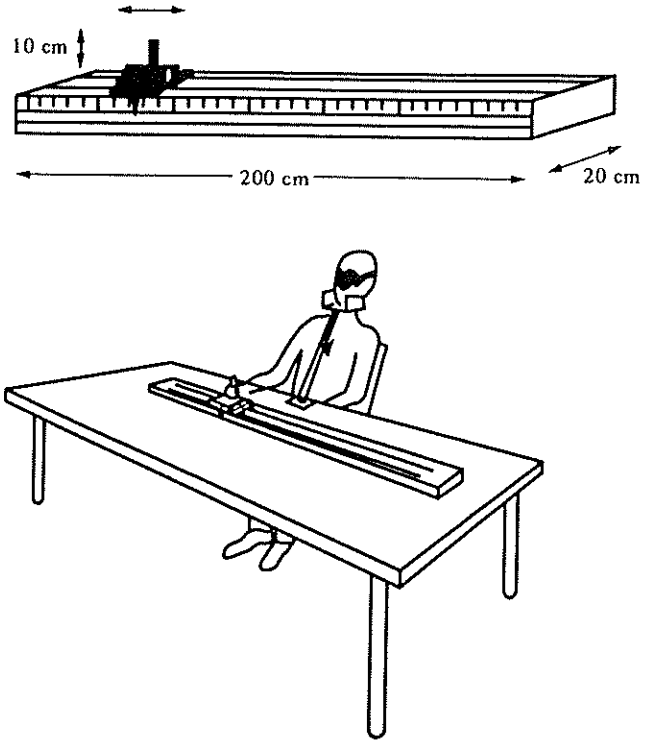

Fig. 1. Apparatus.

Apparatus and procedure

Dick *et al.*'s procedure was reproduced [13]. The movements were performed on a linear positioning apparatus. This consisted of a rectangle equipped with a handle, sliding on two rails. The rails were mounted horizontally and parallel to each other (8.0 cm apart) on a wooden base (2 m × 20.0 cm). The rectangle was 16.0 cm in length, 9.0 cm wide and 1.0 cm in height above the rails. It slid on four small grooved wheels designed to move smoothly along the top of the rails. The handle was a stick (10.0 cm long, 2 cm in diameter) set vertically in the centre of the moving slide and which was held by the subject when performing the movements. Attached to both sides of the slide were L-shaped plates which extended below the rails to prevent the slide from either slipping or being lifted off the tracks. A point fixed to the experimenter's side of the slide moved along a metric scale so that exact length of the subject's movement could be recorded to the nearest millimeter. The noise produced by the movement of the slide was reduced by covering the tops of the rails with tape. A movable clamp situated on the rails allowed the experimenter to control the end location of the constrained movement.

All the subjects were tested individually in the same room, free from external distractions. Subjects were told at the beginning of the session that the task involved remembering motor movements. They were seated in a straight-back chair facing the linear positioning apparatus which rested securely on a table. The apparatus was positioned so that with the right arm outstreched at approximately 90° to the body, the handle was at the 42 cm mark on the tracks. Movements were made in a right to left direction. During the movement, some flexion of the elbow was permitted but the elbow was not allowed to rest on the table. An adjustable chin rest was used to keep the subjects' head immobile, thereby ensuring that the movements involved only the subjects' arm and not the trunk. The subjects' free hand was kept on their lap during all movements (Fig. 1).

Prior to the experimental trials, subjects were shown the apparatus and instructed to move the slide in the range 50.0–110.0 cm. They were told that they should spread their movements throughout the entire available range. When the instructions were understood, the subject was blindfolded. Each trial involved a criterion movement, a retention interval, and a recall or reproduction movement. In the first part of the experiment, the criterion movement was performed with the dominant (right) hand and the reproduction movement was performed with the same (right) hand. In the second part of the experiment, the criterion movement was performed with the left hand and the reproduction movement was performed with the opposite (left) hand. The preselected (self-generated by the subject) and constrained (imposed by the experimenter) trials were differentiated in the following ways.

Preselected (self-generated) trials. Each trial began with the instructions to grasp the handle and select the endpoint or location along the rails where the subjects wished to move the slide. The parameters of the criterion movement were set by the subjects themselves with the constraint that during trials, the movements should be dispersed throughout the entire available range and that the subjects should avoid making a series of similar length movements in successive trials. The command "Select" was given to ensure that the subjects preset the movement before initiating it. Three seconds later, on the command "Move", the subjects moved the slide to the preselected location. After holding the slide steady for 3 sec at this location, the subjects were told to "Release" the handle and place their hand back on their lap. At this moment, the experimenter recorded the endpoint of the movement and returned the slide to the starting position. Then the subjects took the handle again to replicate the criterion movement. Prior to releasing the handle, the experimenter again recorded the length of the reproduction movement, thereby completing the trial.

Constrained trials (imposed by the experimenter). The procedure was essentially the same as described for the preselected trial but with two exceptions: 1—the command "Ready" was substituted for the command "Select"; 2—the experimenter, instead of the subjects, determined the end location of the criterion movement by placing a clamp on the rails. This clamp was removed prior to making the reproduction movement. The length of the criterion movements presented to the subjects in the constrained trials was matched to those chosen by them in the corresponding preselection trials. So the subjects made identical criterion movements but under different modes of presentation.

For both preselected and constrained conditions, subjects performed 12 trials under each of the three retention conditions:

(1) Immediate recall condition: The replication movement began as soon as the experimenter returned the slide to the start position.
(2) Fifteen-second unfilled-retention condition: The subjects were instructed simply to think about the end location of the criterion movement (i.e. silent rehearsal).
(3) Fifteen-second filled-retention condition: During this interval the subjects were required to perform a digit subtraction task. This attention-demanding task involved counting backwards by threes (or by twos if it was too difficult for certain patients) from a two-digit number given by the experimenter. Counting began immediately after the subjects released the handle following completion of the criterion movement and ended with the command "Grasp the hand" in preparation for making the reproduction movement.

Completing the 72 (12×3) trials of each part of the experiment (part 1: reproducing the movement with the same limb, part 2: reproducing the movement with the opposite limb) took about $1\frac{1}{2}$ hr. As the distances used in constrained trials were identical to those used in preselected trials, the 36 preselected trials were completed first, followed by the constrained trials, after a short rest period. The order of the three retention conditions was counterbalanced across subjects. In addition to the learning practice at the beginning of the session, subjects were allowed to make between three and five practice trials at the beginning of each retention condition. Usually, the subjects were able to master the procedures and become familiar with the task after only a few practice attempts. The same-limb condition was always performed first (part 1) as we were not sure that our out-patients would be able to achieve the two parts in the same day. Then the third parameter was introduced: changing hands between the criterion movement and the recall or reproduction movement. Performing the reproduction movement with the contralateral limb makes it more difficult to use the stored kinesthesic cues which have to be transformed into a code which can be effectively used by the opposite limb [54, 58].

The purpose was to check whether HD patients encoded the movement at the same level as controls. If they formed a plan, mental image or strategy on preselected trials allowing them to meaningfully encode their action, then the preselected effect could remain even in the switch-limb condition. On the other hand, if the actual physical or kinesthesic information from the criterion movement provides the majority of the information to recall, then the switch-limb procedure should eliminate the preselection effect in HD. For this second part of the experiment, the subjects, after a rest, sat facing the apparatus so that the midline was directly in front of the movement track and the movement range could be completed easily with both arms. The criterion movement was performed with the right hand and the reproduction movement with the left hand by all of the subjects. A new set of 72 trials was carried out (36 preselected then 36 constrained movements with three conditions of retention intervals), according to the same design as described above.

Statistical design

There are several kinds of error which have to be considered in the analysis of movements: the *absolute error* is the unsigned difference between the target and the reproduced movement, the *constant error* is the signed difference between the target and the reproduced movement representing directional bias, and the *variable error* is the standard deviation around the constant error representing consistency. Absolute errors have been preferred as a measure of performance, and its use as an assessment of recall-schema strength is justifiable [49]. However, according to Dick *et al.* [13], it is preferable to use multiple scores, because the absolute error is a weighted combination of constant and variable errors. Therefore, for each subject, the three errors were computed (in cm). Furthermore, each measurement being a difference between the criterion movement, whose length varied notably, and the reproduced movement, we studied a fourth index of performance: the *proportional value* according to the formula:

100 × absolute error/criterion movement. Thus, the proportional value expresses the reproduced movement as a percentage of the initial movement. For each subject, 12 scores were derived, each being the mean value of 12 responses, according to the three variables: "hand" (the movement was reproduced with the same vs the contralateral hand); "delay" (the movement was reproduced immediately vs after an unfilled delay vs after a filled interval) and "source" (the initial movement was generated by the subjects themselves vs imposed by the experimenter). A mixed, $2 \times 2 \times 3 \times 2$, four-way analysis of variance (Anova) was computed. The between-subject factor was the group (HD vs HD-Controls); $n = 12$ subjects per sample), and the three within-subject factors were the hand (2), the delay (3) and the source (2). Multiple comparisons of means were then computed by means of the Newman Keuls test. For all analyses, results with $P < 0.01$ were considered statistically significant.

RESULTS

The mean and standard deviations of criterion movements, absolute, constant, variable, and proportional errors for both samples are shown in Table 2.

Criterion movements

A preliminary analysis was performed to see if criterion movement length was different in HD and in HD-Controls in the various conditions. A mixed $2 \times 2 \times 3$ three-way ANOVA was computed. The between-subject factor was the group, the two within-subject factors were the hand and the delay, criterion movements being the same in the conditions "generated" and "imposed". This analysis showed a significant hand effect: [$F(1, 22) = 45.08$, $P < 0.0001$]—the criterion movement executed by the left hand was shorter than that by the right hand, whatever the group and the delay.

Absolute errors

In the ANOVA, each main factor and one one-way interaction reached a significant threshold. Thus, HD patients performed worse than HD-Controls [$F(1, 22) = 26.01$, $P < 0.0001$), the performance was better with the ipsilateral than with the contralateral hand [$F(1, 22) = 26.94$, $P < 0.0001$], and movements generated by the subject were reproduced better than movements defined by the experimenter [$F(1, 22) = 21.14$, $P < 0.0001$]; the main delay effect [$F(2, 44) = 12.17$, $P < 0.0001$] showed that the immediate condition was better than the unfilled and the filled interval not differing from each other.

However, the main delay and group effects were qualified by the significant *delay* × *group* interaction [$F(2, 44) = 5.28$, $P < 0.009$] which is depicted in Fig. 2. The *post-hoc* analysis of this interaction indicated: (a) that the main group effect applied to each delay separately; (b) that the main delay effect applied only to the HD patients, but (c) that control subjects were insensitive to the delay. In order to see if there was an effect of the medication, two two-way ANOVAS were performed on the HD group. Patients receiving neuroleptics did not differ from the others [$F(1, 10) = 0.92$, $P = 0.36$], nor did patients receiving bromocriptine [$F(1, 10) = 0.46$, $P = 0.51$].

Constant errors

Analysis of the constant errors indicated a significant source effect [$F(1, 22) = 16.87$, $P < 0.0005$]. These constant errors were larger when the criterion movement was imposed by the examiner than when it was self-generated by the subjects.

Variable errors

Analysis of the variable errors revealed a significant group effect [$F(1, 22) = 27.79$, $P < 0.0001$], hand effect [$F(1, 22) = 20.12$, $P < 0.0002$] and delay effect [$F(2, 44) = 17.77$,

Table 2. Criterion movements and error scores [mean (S.D.)] for Huntington's disease patients (HD) and matched-control subjects (HD-Controls)

	Same limb						Switched-limb					
	Immediate		15″ unfilled		15″ filled		Immediate		15″ unfilled		15″ filled	
	Presel.	Imp.	Presel.	Imp.	Presel.	Imp.	Presel.	Imp.	Presel.	Imp.	Presel.	Imp.
HD												
Criterion movement (cm)	38.32 (7.32)	id	40.85 (7.11)	id	38.06 (7.23)	id	28.31 (9.32)	id	28.34 (9.54)	id	28.18 (8.93)	id
Absolute errors (cm)	3.31 (1.47)	4.01 (1.42)	5.15 (3.09)	5.23 (3,09)	4.59 (1.69)	5.12 (1.44)	4.90 (1.64)	5.45 (2.22)	5.65 (1.51)	7.42 (3.54)	6.56 (2.35)	6.73 (2.39)
Constant errors (cm)	0.67 (1.37)	0.76 (2.11)	0.55 (1.67)	1.28 (1.76)	0.86 (2.05)	1.43 (2.62)	0.59 (2.31)	1.63 (2.38)	0.95 (2.60)	3.91 (4.45)	0.53 (2.80)	1.87 (2.85)
Variable errors (cm)	4.07 (2.13)	4.71 (1.83)	6.57 (4.57)	6.09 (4.25)	5.73 (2.11)	6.10 (1.46)	5.85 (2.40)	5.90 (2.72)	6.91 (2.28)	7.48 (3.55)	8.23 (2.93)	8.24 (2.46)
Proportional Absolute errors (%)	10.88 (6.94)	13.28 (7.30)	19.60 (19.05)	18.63 (17.72)	16.44 (7.23)	19.03 (7.94)	25.07 (21.37)	31.05 (25.20)	34.19 (31.58)	43.65 (39.27)	39.74 (32.80)	30.28 (15.39)
HD-Controls												
Criterion movement (cm)	37.72 (8.00)	id	37.28 (9.38)	id	36.23 (8.16)	id	29.92 (3.24)	id	29.27 (3.58)	id	28.85 (4.49)	id
Absolute errors (cm)	1.62 (0.45)	2.35 (1.00)	1.96 (0.62)	2.79 (0.96)	2.30 (0.91)	2.20 (0.60)	2.82 (0.97)	3.57 (1.91)	3.01 (0.93)	3.65 (1.30)	3.27 (0.86)	3.86 (1.58)
Constant errors (cm)	0.24 (1.01)	1.03 (2.14)	−0.20 (1.42)	0.47 (2.03)	−0.36 (1.05)	−0.37 (1.28)	0.06 (1.15)	1.36 (2.14)	0.15 (1.19)	1.55 (2.04)	0.25 (1.07)	0.91 (1.86)
Variable errors (cm)	1.87 (0.44)	2.08 (0.63)	2.11 (0.72)	2.81 (1.04)	2.82 (1.01)	2.69 (0.78)	3.39 (1.37)	3.87 (1.86)	3.63 (1.06)	3.95 (1.33)	4.22 (1.03)	4.65 (2.02)
Proportional Absolute errors (%)	4.89 (1.19)	6.97 (2.20)	6.36 (2.23)	9.22 (3.27)	8.79 (5.50)	7.73 (3.19)	10.03 (2.50)	13.82 (6.50)	11.85 (2.77)	16.09 (4.86)	13.04 (5.57)	17.20 (7.38)

Presel. = preselected by the subject; Imp. = imposed by the examiner.

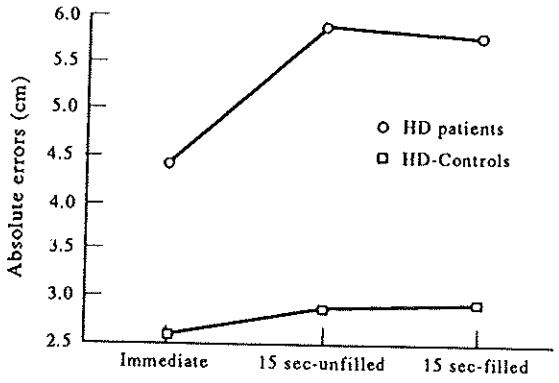

Fig. 2. Effect of the delay on motor memory in Huntington's disease (HD) patients and Controls.

$P<0.0001$]. The variable errors were larger in HD patients than in HD-Controls, when the subjects recalled the movement with the contralateral hand than with the hand which performed the criterion movement and when the movements were recalled after a delay (whether filled or unfilled).

Proportional errors

Analysis of the proportional value of the error revealed a significant group effect [$F(1, 22)=8.89$, $P<0.007$]: proportional errors were larger in HD patients than in HD-Controls; hand effect [$F(1, 22)=19.66$, $P<0.0002$]: proportional errors were smaller when the recall movements were performed with the same hand as the criterion movement than with the contralateral hand; source effect [$F(1, 22)=15.53$, $P<0.0007$]: proportional errors were larger when the criterion movements were imposed by the examiner than when they were preselected by the subjects.

DISCUSSION

These results show that HD patients performed significantly worse and were more disturbed by the delay on the recall of a linear movement than controls. HD patients were more inconsistent than controls whatever the conditions. However, HD patients were not more affected than controls by the source condition (imposed vs self-generated criterion movement), whatever the length of the criterion movement and the changing of hands between the criterion and recall movements. This confirms the robustness of the preselection effect, which occurs in the motor memory in HD as in DAT [13]. Absolute errors increased in HD patients when there was a delay between the criterion movement and the recall, whether this delay was filled or not. This was not due to a change in constant algebraic error or increased variability. This effect could be partly explained by a change in the criterion movement amplitudes as the interaction group × delay did not reach significancy when proportional errors were analysed. Criterion movements were slightly larger in the unfilled-delayed than in the immediate recall condition in HD patients, whereas it was the opposite in HD-Controls. However, there was no significant delay × group interaction in the analysis of criterion movements. This delay effect is consistent with CAINE *et al.*'s findings [9] using a Brown–Peterson procedure in which HD patients demonstrate an inability to maintain a memory item trace over a short period for both trigram letters and patterned materials. It

does not seem to be in agreement with MEUDELL *et al.*'s study [41] where HD patients were compared with normal subjects and Alcoholic Korsakoff patients on a Peterson short-term memory task of trigrams recall after a 0 sec retention interval, a 20 sec retention interval filled with counting backwards in ones or twos and a 20 sec unfilled retention interval. The difference between the three groups at the 0 and 20 sec unfilled conditions was not significant although raw data showed a decrease in the latter condition performance in HD patients. The lack of significancy could be due to the small size of the samples (six subjects in each group). Besides, BUTTERS and GRADY [7] showed in a previous Peterson short-term memory task study that contrary to Korsakoff patients, HD patients performed more poorly as the predistractor delay between the stimulus presentation and the beginning of the distractor activity became longer. These findings, again concerning small samples ($n=6$), were interpreted as a failure in HD to utilize additional processing time for rehearsal, but could reflect, as well, their inability to maintain a memory item trace over a short period. However, MEUDELL *et al.* [41] suggest an explanation which fits all these data: "While HD have a normal maintenance rehearsal system, they only extract semantic information for a fixed amount of time, irrespective of the total amount of processing time available, and further, the information that is extracted is lost spontaneously from memory" (p. 509). In addition, if in general, the more difficult the distractor during the retention interval then the worse the subsequent level of performance, this appears to be the case to a lesser extent in HD [41], emphasizing the predominant role of the delay over the impairment of rehearsal or semantic processing in these patients.

EXPERIMENT 2: PD PATIENTS

METHOD

Subjects

Twelve right-handed out-patients suffering from Parkinson's disease (four women and eight men) took part in the study. Mean age was 59.1 years (S.D. = 5.1, range: 52–72). Mean duration of the disease was 5.8 years (S.D. = 3.5, range: 2–13) (see Table 3). All the PD patients satisfied the diagnostic criteria of idiopathic PD, i.e. at least two of the following signs with progressive onset: akinesia, rest tremor, rigidity or postural instability, and the absence of any other condition that may produce signs of parkinsonism. Exclusion criteria were cerebellar and oculomotor

Table 3. Clinical characteristics of Parkinson's disease patients

	Sex	Age (years) at test	Age (years) at onset	Duration	Stage (Hoehn & Yahr)	Movements	URSP	Level of education
1.	M	54	52	2	1	Tremor	11	1
2.	W	61	48	13	2.5	Tremor	32	1
3.	W	59	49	10	2	Ak-Hypert	35	3
4.	M	52	49	3	1.5	Tremor	23	3
5.	M	60	54	6	2	Tremor	34	1
6.	M	60	57	3	2	Tremor	32	1
7.	M	59	56	3	2	Tremor	43	3
8.	W	63	57	6	2.5	Tremor	51	2
9.	M	55	53	2	1	Tremor	27	2
10.	M	72	63	9	3	Ak-Hypert	51	2
11.	W	56	51	5	2.5	Tremor	30	1
12.	M	58	50	8	2	Ak-Hypert	32	2

Ak-Hypert = akinesia-hypertonia, UPDRS = Unified Parkinson's Disease Rating Scale.

dysfunction, dysautonomia or any sign evocative of other degenerative parkinsonian syndromes; head injury, history of thyroid disease, diabetes, major psychiatric disorder, psychoactive medication other than L-dopa, excessive alcohol consumption, or any other condition known to impair cognitive function other than PD. No patient was demented according to DSM-III—R criteria [3] and none scored less than 50 on the Modified Mini-Mental Scale [40] or than 135 on the Dementia Rating Scale [39]. The signs were predominant on the right side in eight cases and on the left side in four cases. Mean HOEHN and YAHR scale [26] was 2 ± 0.6 (range: 1–3), the score on the Unified Rating Scale for Parkinsonism [16] was 33.4 ± 11.2 (range: 11–51). All the patients were treated for Parkinson's disease and only for that (most often with the association of levodopa-dopaminergic agonist). They were tested when the felt in their best shape, usually in the very early afternoon.

Twelve right-handed control subjects were matched for sex, age and educational level to the PD patients (PD-Controls). All of them scored at least 28 in the MMSE [17]. They executed the motor memory task in exactly the same conditions as the patients.

Procedures

The procedure was strictly the same as described in Experiment 1.

RESULTS

The mean and standard deviations of criterion movements, absolute, constant, variable, and proportional errors for both samples are shown in Table 4.

Criterion movements

A preliminary analysis was performed to see if criterion movement length was different in PD and in PD-Controls in the various conditions. No effect reached significancy.

Absolute errors

In the ANOVA with group as the between-subject factor and hand, source and delay as the within-subject factors, there was no significant main effect of group. The three within-subject main factors were significant. The performance was better with the ipsilateral than with the contralateral hand [$F(1, 22) = 17.68$, $P < 0.0004$]. There was a hand × group interaction [$F(1, 22) = 5.25$, $P < 0.03$] which is illustrated in Fig. 3. The *post-hoc* analysis showed that absolute errors were not different in PD patients and in PD-Controls when they used the same hand for the criterion and the recall movement but the PD patients performed significantly worse than the PD-Controls when they switched hands.

Movements generated by the subject were reproduced with better accuracy than movements imposed by the experimenter [$F(1, 22) = 13.88$, $P < 0.0015$]. There was no significant group × source effect interaction [$F(1,22) = 2.71$, $P < 0.12$]. The main delay effect [$F(2, 44) = 11.55$, $P < 0.0001$] showed that the movements were better reproduced in the immediate condition than in the delayed (unfilled or filled) condition.

Constant errors

Analysis of the constant errors indicated a significant hand effect [$F(1, 22) = 9.34$, $P < 0.006$] and source effect [$F(1, 22) = 11.63$, $P < 0.0025$]. These constant errors were larger when the subjects recalled the movement with the contralateral hand than with the hand which performed the criterion movement, and when the criterion movement was imposed by the examiner than when it was self-generated by the subjects. There was a significant hand × source interaction [$F(1, 22) = 10.13$, $P < 0.005$]. Constant errors were larger in the contralateral imposed condition than in all the other conditions which did not differ.

Table 4. Criterion movements and error scores [mean (S.D.)] for Parkinson's disease patients (PD) and matched-control subjects (PD-Controls)

	Same limb						Switched-limb					
	Immediate		15″ unfilled		15″ filled		Immediate		15″ unfilled		15″ filled	
	Presel.	Imp.	Presel.	Imp.	Presel.	Imp.	Presel.	Imp.	Presel.	Imp.	Presel.	Imp.
PD												
Criterion movement (cm)	34.57 (5.26)	id	36.12 (4.96)	id	36.65 (5.71)	id	32.16 (2.22)	id	33.68 (3.67)	id	34.11 (2.94)	id
Absolute errors (cm)	1.81 (0.61)	1.97 (0.76)	1.99 (0.69)	2.61 (0.54)	2.36 (0.66)	2.75 (0.67)	3.36 (1.41)	6.57 (5.11)	3.89 (1.99)	7.67 (5.74)	4.66 (2.26)	8.11 (7.11)
Constant errors (cm)	0.08 (1.12)	0.59 (1.45)	−0.09 (1.17)	0.07 (1.78)	0.08 (1.44)	0.41 (1.97)	1.16 (2.81)	4.92 (6.48)	1.81 (3.39)	6.17 (6.91)	2.84 (3.45)	6.60 (8.45)
Variable errors (cm)	2.11 (0.87)	2.01 (0.34)	2.35 (0.56)	2.87 (0.70)	2.66 (0.73)	3.01 (0.75)	3.18 (1.20)	4.05 (1.42)	3.35 (0.77)	4.87 (1.63)	4.01 (1.34)	4.14 (1.64)
Proportional Absolute errors (%)	5.99 (2.49)	6.84 (2.08)	6.42 (2.44)	8.59 (2.66)	7.39 (1.91)	8.92 (3.15)	11.18 (3.92)	21.72 (15.26)	14.05 (8.90)	25.15 (18.09)	15.44 (7.71)	26.14 (22.22)
PD-Controls												
Criterion movement (cm)	38.49 (8.63)	id	38.45 (10.06)	id	37.00 (9.19)	id	30.50 (3.55)	id	29.87 (3.97)	id	29.88 (5.07)	id
Absolute errors (cm)	1.68 (0.45)	2.62 (1.02)	2.22 (0.74)	3.12 (1.12)	2.47 (0.89)	2.49 (0.92)	2.74 (0.96)	3.92 (1.99)	2.94 (0.66)	3.49 (1.17)	3.36 (0.90)	4.27 (1.92)
Constant errors (cm)	0.29 (1.06)	1.29 (2.45)	−0.08 (1.48)	0.67 (2.49)	−0.21 (1.20)	0.32 (1.75)	0.10 (1.49)	1.63 (2.71)	0.23 (1.44)	1.02 (1.77)	0.64 (1.78)	1.19 (2.95)
Variable errors (cm)	2.03 (0.46)	2.28 (0.71)	2.61 (0.93)	3.14 (1.11)	3.14 (0.91)	2.95 (0.86)	3.04 (1.29)	3.81 (1.83)	3.65 (0.80)	3.89 (1.43)	3.87 (1.20)	4.87 (2.00)
Proportional Absolute errors (%)	4.96 (1.19)	7.90 (2.71)	7.01 (2.11)	9.85 (3.21)	9.72 (5.79)	8.63 (3.29)	9.88 (2.72)	15.37 (6.52)	11.23 (1.89)	15.23 (4.45)	13.50 (5.55)	17.92 (7.65)

Presel. = preselected by the subject; Imp. = imposed by the examiner.

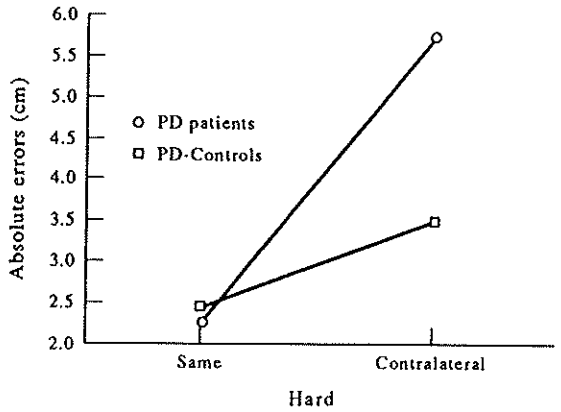

Fig. 3. Effect of the switch of hand on motor memory in Parkinson's disease (PD) patients and Controls.

Variable errors

Analysis of the variable errors showed a significant hand effect [$F(1, 22)=45.12$, $P<0.0001$] (variable errors with the contralateral hand being larger than with the ipsilateral hand), source effect [$F(1, 22)=17.37$, $P<0.0004$] (variable errors for imposed movements being larger than for preselected movements) and delay effect [$F(2, 24)=13.67$, $P<0.0001$] (variable errors in the immediate recall condition being smaller than in the other two delayed conditions not differing one from the other). The variable errors did not differ in PD and in PD-Controls.

Proportional errors

Analysis of the proportional value of the error showed a significant hand effect [$F(1, 22)=26.93$, $P<0.0001$], delay effect [$F(2, 44)=9.81$, $P<0.0003$], and source effect [$F(1, 22)=15.03$, $P<0.0008$]. Proportional errors were larger when movements were reproduced with the contralateral hand, in the filled- and free-delayed condition (not differing from each other) than in the immediate conditions, and when the criterion movements were imposed by the examiner. There was a hand × source interaction [$F(1, 22)=8.78$, $P<0.0075$]: proportional errors were larger when imposed movements were reproduced with the contralateral hand than in any other condition.

DISCUSSION

These results show that, as a whole, the PD patient group did not perform any worse than the control group. The patients selected in this PD population were not demented, were in an early stage of the disease, and were adequately treated with L-dopa and, in most cases, dopaminergic agonist. They were tested when in their best condition. However, there was a significant interaction between group and hand. PD patients were significantly more impaired than controls in recalling a movement when they had to perform the recall of the movement with the other hand. The larger increase of error in PD patients, compared to controls, when the criterion movement was performed with the left hand and the recall movement with the right hand, concerned only the absolute error and was not caused by a change in the constant algebraic error, a change in the amplitude of criterion movements or

by increased variability. This effect was not due to the predominance of the disease on one side since two out of three of the patients had predominant right signs, but suggests a different level of encoding in PD patients and in PD-Controls. SUMMERS *et al.* [56], reporting on the same tasks, indicated that, whereas kinesthetic signals pertaining to joint position and movement extent were informative recall sources under same limb conditions, a variety of cognitive "abstract" strategies are used under switched-limb conditions (for example the use of a familiar metric system to verbally label distance, or a visual image of distance more or less combined with the use of the centre of the body as a reference to aid the coding of movement endpoints). Their experiments suggested that healthy subjects exhibit considerable flexibility in the coding of movement, with the choice of strategy depending on the particular movement cues available. The lack of flexibility in the coding of movement according to the available cues could account for the difficulty of PD patients to recall the movement in the switched-limb condition.

In recent studies, LEONARD and MILNER [34, 35], showed that the right frontal lobe was involved in encoding and recall of movements. Parkinson's disease has been suggested to decrease the output of the basal ganglia to the frontal cortex [2]. It would thus not be surprising that parallels could be noted between the consequences of frontal damage and Parkinson's disease. It must be noted that a difficulty in interhemispheric transfer may be seen in PD patients [31, 57] which could explain the difficulty that PD patients have in recall movements with the contralateral hand.

Comparison between HD and PD

As both control groups (HD-Controls and PD-Controls) did not differ statistically in any of the results [except for age $t(22) = -3.87$, $P < 0.0008$], a four-way ANOVA was computed to check more directly for the different patterns of performance between HD and PD patients. The between factor was the group (HD vs PD), and the within-factors were the hand, the source and the delay.

Absolute errors. There was only a tendency toward a significant group effect [$F(1, 22) = 3.45$, $P < 0.077$] and no significant interaction.

Constant errors. There was a tendancy toward a significant hand × group interaction [$F(1, 22) = 4.76$, $P < 0.045$]. Constant errors were greater in PD patients in the switched-limb condition than in any other condition.

Variable errors. There was a significant group effect [$F(1, 22) = 26.84$, $P < 0.0001$]: variable errors were larger in HD than in PD patients. Furthermore, there was a delay × group interaction [$F(2, 44) = 5.34$, $P < 0.009$]: variable errors were larger in HD than in PD in the three delay conditions; no delay effect was significant in PD; variable errors were smaller in the immediate recall condition than in the other two delay conditions which did not differ in HD.

Proportional errors. No group effect and no interaction involving the group was significant.

Thus, when comparing directly PD and HD, no difference reached statistical significance, except for the variable errors. This suggests that although clear different effects appear when HD and PD patients are compared to matched controls, these effects are not so strong when the two groups of patients are compared together. One cause could be the greater variability in patients than in healthy controls which would need a further study with more subjects. Another possibility is that Huntington's and Parkinson's diseases, both being consequences

of basal ganglia dysfunction, have different but also common patterns of cognitive impairment.

GENERAL DISCUSSION

When compared to matched-controls, HD and PD patients displayed a different pattern of memory efficiency for linear movements. They all performed better when they themselves preselected the criterion movement than when it was imposed by the experimenter, as observed in control subjects and in DAT patients [13]. However, this was especially notable in PD patients. Furthermore, the delay and the hand switching did not affect HD and PD patients in the same way. The delay did not impair recall of movement in PD patients more than in controls whereas it affected more significantly the recall in HD patients than in controls. On the contrary, switching hands between the criterion and the recall movements impaired more significantly the performance of PD patients than controls, whereas this did not affect HD patients more than controls.

STELMACH *et al.* [54] demonstrated in normal subjects that recall in the preselected condition was superior to that in the constrained and passive conditions, which showed no difference, suggesting that "afferent location information *per se* was not totally responsible for recall accuracy" (p. 745). Several interpretations have been made to explain the superiority of the recall movement when the criterion movement was subject-selected than when it was imposed. The hypothesis related to joint receptors, muscular tension, role of the impact on the mechanical stop in the constrained condition was ruled out by STELMACH *et al.*'s experiments [54], as well as KELSO [32]. It was suggested that the addition of preselection allows the subject to code location information more efficiently, because of a stronger central representation. DEIBER *et al.* [11] have shown with PET that when subjects prepare their movement before the trigger stimulus (tasks with internal cues), there was a greater activation in the supplementary motor cortex than when they could not prepare their movement (tasks with external cues). More generally, the likelihood of remembering an event depends on how well the event is encoded [59]. Numerous experiments in the verbal-memory literature [15, 52], comparing recall of internally and externally generated information, have consistently shown an advantage for the former class of information. Our data argue for the capability of HD and non-demented PD patients, as well as DAT patients, to take advantage of the generation effect, and, even more, compensate for their deficit via inherent task properties according to the classification scheme of the concept of "compensation" described by BÄCKMAN [4].

Our results showed that counting backwards had no significantly greater effect than free-delay on the accuracy of recall movements. This disagrees with DICK *et al.* [13] but it is in agreement with a number of previous studies [29, 54, 58]. In the verbal memory literature, counting backwards is a strong attention-demanding task that seemingly fills the limited channel. A verbal interpolated task can interfere with recall accuracy when a relevant verbal label is a useful strategy to assist the recall of location, such as time on a clock with an apparatus displaying arc of circle moving [35]. JONES [30] found that only recall of self-generated movement was affected by verbal processing. This was not confirmed in the third experiment of STELMACH *et al.* [54] where 15" of counting backwards between the criterion and the recall movement affected significantly the performance of the subjects whatever the conditions of encoding (preselected or imposed). In the conditions of STELMACH *et al.*'s study, very similar to the one reported here, the representation in memory, enhanced by the

preselected condition, was not influenced by counting backwards either. This suggests that this memory representation does not require much central verbal processing capacity. This is in agreement with previous studies [46, 63] which found that interpolated digital information processing has no systematic effect on the recall of a specific kinesthetic event. Retention of a single movement does not seem to depend on the availability of central processing capacity. Thus, neural–behavioural mechanisms for digital and kinesthetic short-term memory could be independent.

The schema theory of motor learning [49] comprises a recall side and a response recognition side. Recall schema selects the values of the movement parameters that specify the movement to be made like force, duration, amplitude, and the response recognition schema evaluates the correctness of the movement that is made [cf. 1]. It is not clear, yet, whether linear positioning depends upon the recall or upon the recognition schema. Probably both systems are involved but in various proportions depending on the conditions of the procedure [49]. Moreover several cues such as distance and location are available at execution and reproduction of criterion movements, submitted to different facilitative effects [28]. Thus, motor short-term memory may be impaired in various ways. This could explain, in part, the differences in this reported study between HD and PD patients known to have different patterns of memory impairment. Our design does not permit to discriminate what cues are used by the subject: distance or location, which are represented by qualitatively different types of memory codes [32] which may interact [61]. DICK [14] showed that DAT patients have more difficulty in encoding and retaining information about the movement direction than its distance. He suggested that these results reflected that DAT patients have more difficulty in encoding the conceptual than the perceptual features of a movement.

Both the HD and the PD patients in our study were in the early stage of the disease. In the early stages of PD, pathological and neurochemical changes are mostly restricted to the substantia nigra and striatum, with marked dopamine depletion limited to the putamen, while the caudate nucleus is relatively spared [37, 43]. On the contrary, in the early stage of HD, the caudate nucleus is the main site of degeneration and, with advancing illness, the putamen, and pallidum become involved [19]. If those diseases do involve the basal ganglia, and especially the striatum, known to play a role in cognitive and motor control, the differences in impairment may contribute to a better knowledge of the role of the striatum, whereas striatal pathology may be heterogeneous in the early stages of the disease. Besides, caudate dysfunction is thought to be the critical determinant of motor skill learning deficits in PD [21, 23].

In conclusion, these results suggest the existence of distinct forms of motor memory impairment among the subcortical neurodegenerative diseases, which may be dependent upon distinct neuroanatomic or neurochemical systems.

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