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* Monash University, Clayton, Australia * Huntington's Disease Clinic, Department of Psychiatry, University of Melbourne, Australia

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Initiation and Execution of Movement Sequences in Those Suffering From and At-Risk of Developing Huntington's Disease*

John L. Bradshaw1, James G. Phillips1, Clare Dennis1, Jason B. Mattingley1, David Andrewes2, Edmond Chiu2, Jane M. Pierson1, and Judy A. Bradshaw1

1 Monash University, Clayton, Australia
2 Huntington's Disease Clinic, Department of Psychiatry, University of Melbourne, Australia

ABSTRACT

Recent research has shown that Huntington's disease (HD) causes problems in the initiation and execution of movement (akinesia, bradykinesia): information which is useful in documenting the functional progression of the disease. The present experiment used a sequential movement task to characterize such impairments. Eighteen patients diagnosed as suffering from HD, and a similar number of matched At-Risk (AR) and Normal control subjects, performed sequential button pressing tasks, under varying amounts of visual advance information. Specific dimensions of motor control were examined (hand, direction). Movement initiation and in particular movement duration were useful indicators of the functional progression of the disease, and also detected anomalies of performance in some AR individuals. Impaired motor programming was indicated by patients' difficulty in initiating movements in the absence of external visual cues, and their problems in utilizing advance information to control movement. Patients had specific deficits in initiating movements with the nonpreferred hand, and directional movement asymmetries were accentuated. The results suggest that HD causes difficulties at three discrete levels: in utilizing advance information, in the initiation and in the spatial representation of movement.

Huntington's disease (HD) is an inherited neurodegenerative disorder. The disease is transmitted by a completely dominant autosomal gene near the short arm of chromosome 4 (Gusella et al., 1983). While the mechanisms of transmission are understood, there remains a need to document the functional losses that occur

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Address correspondence to: Dr. J.L. Bradshaw, Department of Psychology, Monash University, Clayton, Victoria, 3168, Australia.

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during the progression of the disease (Penney et al., 1990; Shoulson & Fahn, 1979). Recent observations suggest that HD causes akinesia and bradykinesia (difficulty initiating and maintaining movement; Hefter, Homberg, Lange, & Freund, 1987; Thompson et al., 1988), in addition to the characteristic chorea, psychiatric symptoms, and dementia.

Akinesia and bradykinesia are important since they are reported to be more debilitating than chorea, and may be better indicators of functional ability (Girotti et al., 1984; Girotti, Marano, Soliveri, Geminiani, & Scigliano, 1988). For example, Girotti et al. (1984) found poor correlations between chorea and tests of motor or cognitive functioning, while Girotti et al. (1988) found significant correlations between reaction time (RT), movement time (MT), and tests of cognitive functioning.

Akinesia and bradykinesia may be useful in describing the functional progression of the disease. Indeed, some patients have been reported to have abnormal response latencies before the onset of chorea (Garnett, Firnau, Nahmias, Carbotte, & Bartolucci, 1984). Abnormalities of motor control may have some predictive value in describing the onset of the disease in patients at risk of developing the disorder (Penney et al., 1990). Although the determination of disease onset is difficult, the longitudinal study of Penney et al. (1990) found that At-Risk (AR) individuals, with abnormal saccadic eye movements and impaired performance of rapid alternating movements, were more likely to develop overt HD within several years.

A consideration of akinesia and bradykinesia in HD patients is therefore of interest because these symptoms are debilitating, and may have some predictive value. (Relative predictive value is discussed in Grafton et al., 1990.) In addition, motor control deficits are of interest because HD may provide information about the motor functions of the basal ganglia (Marsden, 1985; Young, Albin, & Penney, 1989). Theorists have suggested that the nuclei of the basal ganglia may play a key role in both the control of movement and in the acquisition of motor skill (Marsden, 1985; Rothwell, 1987). Marsden (1985) suggested that the symptoms of akinesia and bradykinesia seen in diseases of the basal ganglia reflect an underlying deficit in the programmed control of movements.

However, comparatively few studies have investigated voluntary motor control in HD. Examinations of procedural memory in HD patients revealed deficits in the acquisition of motor skills (i.e., pursuit rotor) (Butters, Salmon, Heindel, & Granholm, 1988; Heindel, Butters, & Salmon, 1988; Heindel, Salmon, Shults, Walicke, & Butters, 1989). Heindel et al. (1988) suggested that patients had difficulty generating appropriate motor programs. This is supported by the observations of Bylsma, Brandt, and Strauss (1990) who found that HD patients demonstrated normal learning curves on a maze task, but had difficulty generalizing their learning and did not improve on predictable Mazes.

HD patients' ability to control their movements may be inferred from RT and MT. For example, Garnett et al. (1984) reported that HD patients had increased response latencies and slower movements during a tracking task, and that patients
were slower when performing repetitive tapping movements. A significant slowing of MT has also been found by Hefter et al. (1987) amongst HD patients and a proportion of AR individuals during isometric extensions and alternating movements of the forefinger. Although there was some RT slowing in HD patients, the effect failed to reach significance. In an investigation into speech planning, initiation and production, Ludlow, Connor, and Bassich (1987) found little effect upon RTs, but considerable changes in duration of syllables, and pauses between phrases and sentences, suggesting that there was little impairment in speech planning or initiation, only in actual control processes. Generally, therefore, MT seems to be more affected by HD than RT.

Given that MT is more consistently affected by HD, it is possible that patients' motor programs are spared, but they have problems accessing and utilizing them. The programs for both simple movements (Hallett, 1983; Marsden, Obeso, & Rothwell, 1983) and complex movements such as speaking (Podoll, Caspary, Lange, & Noth, 1988; Wallesch & Fehrenbach, 1988) and writing (Podoll et al., 1988) appear to be present in patients with HD, but these patients have difficulty in initiating and executing voluntary movements (Hefter et al., 1987), and their actions are disrupted by a variety of involuntary movements (e.g., chorea). Thus, while the shape and form of movements remains intact, HD patients appear to have problems controlling specific dimensions of movement (e.g., limb, direction, extent, duration). There is, therefore, a need for HD research to examine the preparation and control of specific dimensions of movement (see Zelaznik & Hahn, 1985).

The aim of the present study was to extend the earlier investigations of voluntary movement control by examining the initiation and execution of sequences of voluntary movements while systematically manipulating the availability of advance information. We assessed the ability of HD patients, AR individuals, and Normal controls to initiate and execute movements made with the preferred and nonpreferred hand. Each hand performed a series of movements, from left to right and right to left, under various conditions of advance information. The task required that subjects press a sequence of buttons in response to visual (light) cues. A range of cuing conditions was employed to vary the extent to which movements could be prepared in advance (programmed). The time that the buttons were held down (down time or DT) reflected in part the amount of preparation subjects required before initiating a movement. The time spent moving between buttons (movement time or MT) provided an index of the amount of time required to guide the fingers to a button.

We examined subjects' ability to use advance information and to perform movements which varied along dimensions of direction (left, right) and hand used (left, right) so as to determine those factors that characterize movement initiation, control, and execution in HD. We also considered whether measures of performance (DT and MT) were related to the functional progression of the disease, and whether there were possible anomalies of movement performance in certain individuals within the AR group.
Subjects
Fifty-four dextral subjects participated, comprising three equal groups of 18, with equal numbers of either sex in each group: HD patients, AR subjects, and Normal controls. (Writing hand was used as the criterion for dextrality.) Subjects were cross-matched for age, educational level, occupation, and scores on the New Adult Reading Test (NART; Nelson & O'Connell, 1978). Details of the three groups may be found in Table 1. There were no significant differences between groups.

The HD patients had previously been diagnosed as suffering from the condition on the basis of a positive family history and presence of choreiform movements. In most instances, presence of striatal atrophy in computed tomographic scans was used to confirm diagnosis. Most patients exhibited hypotonia, and none the akinetic Westphal variant of HD. Apart from one patient aged 19.5 years with symptoms rated as mild (i.e., an "early-onset" type with paternal inheritance), the subjects ranged in age from 35.6 to 58.3 years. Patients’ symptoms had previously been independently rated by staff of the Huntington’s Disease Clinic, University of Melbourne, in the course of their treatment, using a scale of functional capacity (Shoulson & Fahn, 1979). Patients’ symptoms ranged from mild (n = 12) or moderate (n = 5) to severe (n = 1). One third of the patients were on prescribed neuroleptic drugs (Haloperidol, Dartalan, Melleril), and one a tricyclic antidepressant (Imipramine). (Thompson et al., 1988, reported that movement slowing in HD was independent of neuroleptic treatment.)

The 18 AR subjects were all first-generation offspring of patients with a definite diagnosis of HD. None showed evidence of choreiform movement, memory problems, feelings of anxiety or depression. The 18 Normal controls were not genetically related to anyone with HD and, like the AR subjects, were without clinical evidence of perceptual or cognitive deficits. All participants had normal or corrected-to-normal vision.

Apparatus and Task
Subjects were required to move their hand along a board (480mm long by 100mm wide), pressing a series of buttons (see Figure 1). The board was placed in the frontoparallel plane, with the centre directly opposite the midline of the seated subject, whose chair height and distance from the apparatus was individually adjusted for comfort.

Subjects pressed two single buttons (first $S_1$, then $S_2$) to initiate the task. They then progressed along the board through the 10 pairs of buttons, choosing and pressing one button from each successive pair, before pressing a single final button to end the task ($F_1$). Adjacent buttons were 30mm apart. Buttons were 13mm in diameter and situated in a translucent annulus recessed into the board. Red light-emitting diodes (LEDs) provided visual cues as to the sequence of buttons to be pressed by the subject. The LEDs were embedded within the annuli, and were progressively illuminated, one at a time. An IBM-compatible XT Lap Top computer controlled the sequence of lights, and measured the

<table>
<thead>
<tr>
<th>Table 1. Demographic Information for Subjects in each Group [Mean (SD)].</th>
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<tbody>
<tr>
<td>HD patients</td>
</tr>
<tr>
<td>Years diagnosed</td>
</tr>
<tr>
<td>Age (yrs.)</td>
</tr>
<tr>
<td>Education (yrs.)</td>
</tr>
<tr>
<td>NART IQ</td>
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</tbody>
</table>
Fig. 1. Tapping board used in the experiment. Subjects pressed the buttons S1 and S2, and then they chose and pressed one button from each successive pair, before pressing the button (F).

time from depression to release of each button (DT) and from release of one button to depression of the next (MT).

Procedure
Subjects were required to move as fast as possible along a sequence of buttons, using either their left or right hand. The orientation of the board was varied, such that subjects moved from left to right or vice versa. The pathway along the board was shown by a sequence of LEDs which cued successive target buttons. At no time was there ever more than one button illuminated. The duration of illumination of buttons was either 250ms or 1,000ms. Duration of illumination was examined in preliminary analyses, but had no effect (main or interaction), so data were combined across durations, and duration was dropped from further analyses.

Each pathway across the 10 pairs of buttons on the board consisted of both linear and diagonal movements. The numbers of linear and diagonal moves between successive pairs of buttons within movement sequences were balanced, such that the total distance in each movement sequence was constant. There were eight fully counterbalanced pathways. Average DT and MT for the 10 buttons in the sequence were calculated. If an incorrect button was pressed, or one was missed, that trial was automatically abandoned and subsequently repeated.

The amount of advance information was manipulated, to vary the amounts of preparation that are possible. To vary the possible amounts of advance information (and, consequently, preparation time), three types of cue were employed (see Table 2):

When no target information is available in advance, subjects have to prepare their movement on-line, during its execution. In cue condition A, the next button in the series to be depressed was illuminated by the computer only when the present button was released (i.e., there was no advance information).

When target information is made available before a movement is initiated, the amount of preparation may be partly reflected in the response latency (down time). In cue condition B, the next button in the series to be depressed was illuminated by the computer when the present button was depressed (i.e., one button was prepared in advance).

When target information is made available yet further in advance, the additional amounts of preparation may be further reflected in reductions in DT. In cue condition C, the next button in the series to be depressed was illuminated by the computer when the previous button was released (i.e., two buttons were now prepared in advance).

Experimental factors were combined systematically to produce a Group (HD patient, AR, Normal) by Cue Type (A,B,C) by Hand (left, right) by Movement Direction (left, right) design. There were, thus, 12 experimental conditions for each group of subjects.
Table 2. Amounts of preparation possible with varying amounts of advance information (as indicated by the relative distances between the events described below).

<table>
<thead>
<tr>
<th>Cue</th>
<th>Preparation interval occurs between:</th>
<th>Amount of preparation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Button 1 released Button 2 illuminated</td>
<td>No advance preparation</td>
</tr>
<tr>
<td>B</td>
<td>Button 1 pressed Button 2 illuminated</td>
<td>1 button prepared</td>
</tr>
<tr>
<td>C</td>
<td>Button 1 released Button 3 illuminated</td>
<td>2 buttons prepared</td>
</tr>
</tbody>
</table>

Each condition was presented in a separate block of trials. Pilot testing revealed that HD patients found larger numbers of trials tiring. To avoid undue fatigue, HD patients completed 4 trials per condition (48 in total). All other subjects were able to complete 8 trials per condition (96 in total). Since pilot testing suggested that patients with HD had difficulty starting with Cue C (where most advance information was available), this condition was presented last. This is a conservative procedure, since any practice effects would reduce any differences between cue conditions A, B, and C. DT and MT were analyzed in separate mixed-model 3x3x2 analyses of variance.

RESULTS

Response Preparation
The period of time that the buttons were held down during each movement sequence (DT) reflected the amounts of preparation required by subjects before they could initiate a movement. Patients with HD were akinesic, and spent significantly more time (255 ms) preparing parts of their movement sequence than did AR individuals (111 ms) or Normal controls (105 ms) ($F(2,51) = 27.69, p < .001$).

The significant Group by Cue interaction showed that the three groups were differentially affected by Cue condition ($F(4,102) = 3.67, p < .01$) (see Figure 2A). The Group by Cue interaction was interpreted using Tukey tests. Tests between Cues, for each Group, showed that, for HD patients, only Cue A differed significantly ($p < .05$) from Cue C and that, for the other two Groups (AR and Normal subjects), there were no significant differences. Tukey tests, between Groups, at each level of Cue (A, B, and C) showed that for all three cues HD patients differed significantly ($p < .01$) from both AR and Normal subjects, while the latter two Groups did not differ significantly from each other.

As may be seen in Figure 2A, HD patients were particularly slow at initiating movements, compared to the AR and Normal control groups, in cue condition A (where external visual cues were not available until after the subject had left the
previous button). This result suggests that HD patients were more reliant upon external cues when preparing and initiating a sequence of movements.

The experimental design allowed a consideration of patients' ability to initiate movements with the left or right hand, or to move from left to right or from right to left. There was no effect of direction of movement: Patients and control subjects did not significantly differ in the times they required to initiate movements to left or right. However, a significant Group by Hand interaction showed that the three groups differed in their patterns of hand asymmetry during DT ($F(2,41) = 23.31, p < .001$). While patients with HD were slower at initiating movements made with either hand, the time taken to initiate a movement with the left (nonpreferred) hand (277 ms) was disproportionately slower than the time taken by the right (preferred) hand (233 ms), i.e., there was a left hand inferiority of 44 ms. Although there was also a left hand inferiority in Normal control subjects (11 ms) and AR individuals (12 ms), patients with HD showed greater problems in

![Fig. 2. Mean down time (Figure A) and movement time (Figure B) in milliseconds (ms) for the three groups of subjects across the three cue conditions. Cue A: no advance information; Cue B: 1 button prepared in advance; Cue C: 2 buttons prepared in advance. (Figure A) Patients with Huntington's disease show a DT which is particularly impaired for Cue A. (Figure B) Patients with Huntington's disease show little improvement in MT between Cues B and C.](image_url)
the initiation of movements made with their left hand. Overall, the DT data suggest that HD causes specific problems in the initiation of movements with the left (nonpreferred) hand.

Movement Execution
Preparatory processes serve to link movements into sequences, and to reduce the amount of guidance required during movement. If HD patients are impaired in their ability to efficiently prepare responses in advance, then the amount of guidance required during movement execution may be increased. It has already been observed that HD patients show signs of bradykinesia. This was reflected in the MTs of our HD patients, who took significantly longer to perform a movement sequence (503 ms) than did AR (283 ms) or Normal subjects (263 ms) ($F(2,51) = 10.9, p < .001$).

The effect of Cue (i.e., amount of advance information) was also highly significant ($F(2,102) = 111.4, p < .0001$), with performance on Cue A being the slowest (440 ms), followed by Cue B (340 ms) and Cue C (269 ms). Comparison of cueing conditions allowed an examination of the effects of increasing the amount of advance information upon movement. The Group by Cue interaction was significant, $F(4,102) = 2.63, p < .04$ (see Figure 2B).

Tukey tests showed that, for AR and Normal subjects, all three Cues differed significantly from each other ($p < .01$); for HD patients, there was no significant difference between Cues B and C. Tukey tests between Groups at each level of Cue (A, B, and C) showed that, in every case, HD patients differed significantly from both AR and Normal subjects, at $p < .01$; the latter two Groups did not differ significantly from each other. Thus, the locus of the Group by Cue interaction seems to be the fact that, while AR and Normal subjects showed similar improvements with advance information, this was not the case with HD patients. As may be seen in Figure 2B, patients with HD could not utilise advance information to the same extent as did Normal control and AR subjects. While AR and Normal subjects were able to reduce MT as a function of the amount of advance information available, HD patients were unable to demonstrate a similar improvement. More specifically, patients with HD were less able to use the advance information provided by Cue C to facilitate movement control.

The experiment also provided details of patients' ability to perform movements with the left or right hand, and to move from left to right or right to left. Unlike DT, there were effects of direction upon MT. The significant Hand by Direction interaction ($F(1,51) = 123.53, p < .001$) showed that adductive movements (left to right for the left hand, 328 ms, and right to left for the right hand, 336 ms) were faster than abductive (right to left for the left hand, 365 ms, and left to right for the right hand, 370 ms). This adductive superiority was similar for the left (38 ms) and right (34 ms) hands. However, there was also a significant Group by Hand by Direction interaction ($F(2,51) = 24.8, p < .001$) which indicated that HD patients may have experienced particular difficulties when making adductive movements. HD patients' adductive movements were 68 ms slower than their
adductive movements, while abductive movements made by AR and Normal subjects were only 21 ms and 19 ms slower, respectively.

**Association with Markers of Disease Severity**

From the results presented above, it is clear that HD patients show considerable slowing of their movements. We performed a correlational analysis on the HD patient data to determine if there was a relationship between markers of disease severity, and measures of DT and MT for the three levels of advance information. As may be seen in Table 3, DT and MT were significantly related at all times to functional capacity (Shoulson & Fahn, 1979). In addition, only MT was significantly related to duration of the disease in tasks where on-line control of movement was important (Cue A). When advance information was available (Cue C), so that movements could be prepared further in advance, both DT and MT were now significantly related to duration of the disease.

**Initiation and Execution of Movements in AR Individuals**

We also considered whether any of the AR individuals exhibited anomalous performance characteristics. The AR group is a heterogeneous group; though currently free in a clinical sense from any disability, some will eventually progress to HD. Since HD tends to manifest itself in the middle decades, we would expect rather more than half of the AR group (now in their middle decades) to be safe from developing the disorder. Consequently, we might expect that somewhat less than half of the AR individuals could possibly manifest some of the performance characteristics, perhaps only to a minor degree, of HD patients. Indeed some AR individuals were noticeably slower than control subjects. To illustrate this, data were converted to z-scores, based upon the corresponding means and standard deviations of the normal subjects; this procedure was performed separately for cue conditions A, B, and C. The z-scores greater than 1.65 (i.e., 95th percentile) were considered to deviate from the average performance of Normal

<table>
<thead>
<tr>
<th>Table 3. Relationship between functional capacity, duration of disease, and DT and MT, for the three levels of advance information (advance information increases from A to C).</th>
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<tbody>
<tr>
<td>Cue A</td>
</tr>
<tr>
<td>DT</td>
</tr>
<tr>
<td>Functional Capacity</td>
</tr>
<tr>
<td>Years Diagnosed</td>
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* Significant at .05 level using Kendall’s Tau-B.
Table 4. Numbers of subjects (AR and Normal) whose performance (DT or MT) deviated from the average performance of normal control subjects, for Cue conditions A, B, and C.

<table>
<thead>
<tr>
<th>CUE</th>
<th>DT*</th>
<th>MT*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>At-Risk</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Normal</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* Maximum number of subjects for each column is 18 At-Risk, and 18 Normal.

control subjects. The number of subjects with extreme z-scores for each condition are recorded in Table 4. The performance of several AR individuals (see Discussion) was much slower than the average performance of normal control subjects, particularly on measures of MT and on Cue C. This should suggest that such measures could be useful in documenting the progression of the disease, even among those individuals who are yet to manifest any clinical symptoms.

DISCUSSION

The present study systematically manipulated advance information while HD patients performed sequential movements in an attempt to document the nature and progression of specific deficits in the initiation and execution of movement. Symptom severity correlated with akinesia and bradykinesia (as measured by DT and MT), a finding in accordance with previous suggestions that these symptoms are predictors of functional ability. For example, Hefter et al. (1987) noted significant correlations between measures of movement time and symptom severity, while Girotti et al. (1988) reported significant correlations between RT and cognitive functioning. The pattern of correlations obtained in the present study suggests that the severity of disease is related to deficits both in the utilization of advance information (Cue C), and in the ongoing control of movements (Cue A).

In addition, our data suggest that DT and, especially, MT may be sensitive to early abnormalities of motor control in AR individuals. When compared to matched Normal control subjects, three AR individuals in particular showed a consistent and substantially slower MT, while a further AR individual showed a substantial and consistent slowing of DT. This is in accord with the longitudinal study of Penney et al. (1990), which found that early motor abnormalities (abnormal eye saccades and problems with repetitive alternating movements) can occur before the appearance of chorea, the symptom that is usually required for a diagnosis of HD. The cross-sectional study of Hefter et al. (1987) also found motor abnormalities in AR individuals, but they found that the maximum rate of performance of repetitive alternating movements was not as sensitive an indicator of abnormali-
ties in AR individuals. Heft et al. found that only 18% of AR individuals had abnormalities in their repetitive alternating movements, while 40% of such individuals had abnormal relationships between contraction time and amplitude of isometric contraction.

It is still unclear whether mood, personality, or motor changes occur first in HD (e.g., Bennett & Curiel, 1989; Hall, Bigler, & Rutledge, 1989; Strauss & Brandt, 1990). For example, while depression and dementia have been reported to precede chorea (Bennett & Curiel, 1989; Hall et al., 1989), Strauss and Brandt (1990) did not find evidence of neuropsychological abnormalities in a group of AR individuals (marker positive) on a battery of tests. Our cross-sectional data suggest that measures such as DT and MT, obtained from tasks where advance information is manipulated during sequential movements, could form a useful part of the neuropsychological assessment of HD patients. They may also provide a means of monitoring the functional progression of the disease.

Heindel et al. (1988) suggested that patients with HD have problems generating the programs for movement. Motor programs provide the internal commands and cues for movement guidance. Our data suggest that these cues are disrupted, since HD patients relied more upon external cues during the performance of movement sequences. This was particularly noticeable when target buttons were not cued until the movement was actually initiated (Cue A); under such circumstances HD patients took much longer to initiate each movement.

The function of a motor program is to reduce the amount of ongoing control of movement, in particular, to allow smaller movements to be joined into sequences without feedback. Impairments in the programmed control of movement are indicated both in patients' problems in using advance information, and in their longer MT; this would suggest that they require greater amounts of ongoing control of their movements (see Heindel et al., 1988). Impaired motor programs, and a greater reliance upon the ongoing control of movement, could explain why studies more often report impaired MT than impaired RT in HD patients. The present study found that patients' MT was impaired on average by 240ms, while patients' DT was only impaired on average by 150ms (comparing HD patients with Normal controls).

While Heindel et al. (1988) reported that HD patients may have problems learning motor skills, Bylsma et al. (1990) found more specific deficits associated with the programming of movements. Patients with HD were impaired both in their ability to generalize their learning, and in their ability to use predictive information. This suggests that patients' motor impairments arise from more specific deficits in the control of movements. For example, patients' failure to generalize and transfer a previously learnt program (Bylsma et al., 1990) could be the result of problems choosing the appropriate movement parameters (e.g. extent, direction, limb) for new situations.

The present paper found specific deficits in the initiation of movement. Patients with HD had disproportionate difficulty initiating movements with their nonpreferred hand. (Slow performance with the left hands of HD patients has
also been noted by Garnett et al., 1984.) These deficits in the initiation of movements are unlikely to be a simple result of memory dysfunction (i.e., forgetting cue or task) (Butters, Wolfe, Granholm, & Martone, 1986), since a general memory deficit is unlikely to cause problems in the control of only one hand. (Indeed there were no effects of duration of cue illumination.)

The accentuated inferiority of the nonpreferred hand may be a direct product of the abnormal and excessive patterns of activation of movements in HD patients (Marsden et al., 1983). A proportional increase in the activation of all motor programs would tend to enhance existing hand asymmetries, explaining the exacerbated nonpreferred hand inferiority in HD patients. This heightened activation of all motor programs would, in turn, interfere with the planning or coordination of any particular goal-directed movement. Alternatively the observed nonpreferred hand inferiority in these patients may be an indirect effect of chorea. Chorea could disrupt voluntary movement in these patients, causing a background motor noise, which may result in greater reliance upon the preferred hand. However, the observation that AR individuals may have problems initiating and executing movements (before chorea and a diagnosis of HD has been confirmed), leads to the suggestion that the observed impairments could be a more direct result of problems in the activation of movements.

The present data also reveal specific deficits in the execution (though not the preparation) of abductive movements in HD patients. Abductive movements, whether for spatial or biomechanical reasons, are typically harder to perform than adductive movements (Bradshaw, Bradshaw, & Nettleton, 1990), and choreiform movements could exacerbate such differences in HD patients. Bradshaw et al. (1990) have suggested that adductive superiorities can be explained in terms of movements receiving better spatial representation towards the midline. The impaired performance of abductive movements in HD patients may reflect visuo-spatial deficits. Indeed researchers have reported that HD patients are impaired in tasks requiring visuo-spatial processing (Boll, Heaton, & Reitan, 1974; Caine, Hunt, Weingartner, & Ebert, 1978; Josiassen, Curry, & Mancall, 1983). In particular, Brouwers, Cox, Martin, Chase, and Fedio (1984), in a comparison of patients with Huntington's and Alzheimer's diseases, found that HD patients were impaired in tasks involving manipulations of personal space (Road-Map test) but not in tasks involving extrapersonal perception and construction (copying accuracy: Rey-Osterrieth Complex Figure). Deficits in the activation and spatial representation of movements could partly explain the akinesia and bradykinesia seen in HD patients.

The present study systematically examined the control of sequential movements in HD, an area that, until recently, has received little attention (Heindel et al., 1988; Thompson et al., 1988). Our data showed that measures of akinesia and bradykinesia were sensitive to the progression of HD. Patients with HD were impaired in their programmed control of movements, being more reliant upon external cues, and less able to use advance information. Patients had specific problems both in initiating movements with the nonpreferred hand, and in per-
forming abductive movements, suggesting that the akinesia and bradykinesia in these patients could be a result of impairments in the activation and spatial representation of movement. From the deficits caused by HD we can infer (Marsden, 1985) that the basal ganglia have a role in the activation and spatial representation of movement.

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