Functional asymmetries in the movement kinematics of patients with Tourette’s syndrome

Nellie Georgiou, John L Bradshaw, Jim G Phillips, Ross Cunnington, Mark Rogers

Abstract

Objectives—This study adopted a concurrent task design and aimed to quantify the efficiency and smoothness of voluntary movement in Tourette’s syndrome via the use of a graphics tablet which permits analysis of movement profiles. In particular, the aim was to ascertain whether a concurrent task (digit span) would affect the kinematics of goal directed movements, and whether patients with Tourette’s syndrome would exhibit abnormal functional asymmetries compared with their matched controls.

Methods—Twelve patients with Tourette’s syndrome and their matched controls performed 12 vertical zig zag movements, with both left and right hands (with and without the concurrent task), to large or small targets over long or short extents.

Results—With short strokes, controls showed the predicted right hand superiority in movement time more strongly than patients with Tourette’s syndrome, who instead showed greater hand symmetry with short strokes. The right hand of controls was less force efficient with long strokes and more force efficient with short strokes, whereas either hand of patients with Tourette’s syndrome was equally force efficient, irrespective of stroke length, with an overall performance profile similar to but better than that of the controls’ left hand. The concurrent task, however, increased the force efficiency of the right hand in patients with Tourette’s syndrome and the left hand in controls.

Conclusions—Patients with Tourette’s syndrome, compared with controls, were not impaired in the performance of fast, goal directed movements such as aiming at targets; they performed in certain respects better than controls. The findings clearly add to the growing literature on anomalous lateralisation in Tourette’s syndrome, which may be explained by the recently reported loss of normal basal ganglia asymmetries in that disorder.

Keywords: Tourette’s syndrome; asymmetry; basal ganglia

Gilles de la Tourette’s syndrome is a disorder characterised by involuntary motor and vocal tics. It may be transmitted as an autosomal dominant gene disorder with incomplete penetrance. Various researchers have reported that the lenticular region (putamen and globus pallidus) of the basal ganglia in the left hemisphere is reduced in volume in patients with Tourette’s syndrome compared with a control group. These abnormal asymmetries suggest that basal ganglia in patients with Tourette’s syndrome do not have the volumetric asymmetry (left greater than right) seen in normal controls. Moreover, Hyde et al have more recently shown a significant reduction in right caudate volume, and in left lateral ventricular volume, as well as a loss of the normal lateral ventricular asymmetry in monozygotic twins discordant for the severity of Tourette’s syndrome; six out of 10 severely affected twins had a right ventricle larger than the left. Yazgan et al sought to ascertain whether abnormalities in structural basal ganglia asymmetries have functional significance in Tourette’s syndrome. Patients with Tourette’s syndrome were administered a battery of lateralising neuropsychological tests (line bisection, turning bias, dichotic words, verbal or manual interference). They found that patients with Tourette’s syndrome show a reduction in normal functional asymmetries. Indeed, the issue of abnormal asymmetries in patients with Tourette’s syndrome has long prevailed in the literature. Sweet et al reported that patients with Tourette’s syndrome showed various abnormal motor asymmetries which included lateral impairments of rapid alternating movements. Tourette’s syndrome, similar to Parkinson’s disease and Huntington’s disease, may also involve a deficit in the accurate performance of complex motor programmes. Georgiou et al found that patients with Tourette’s syndrome, compared with controls, were more reliant on external visual cues to execute (rather than to initiate) a motor programme; in consequence, with limited visual guidance their movements progressively slowed with each successive element in the response cycle. Moreover, if no advance information was provided before each successive move, movement execution was slower than that of controls. It may be the case that patients with Tourette’s syndrome (similar to Parkinson’s disease and Huntington’s disease) have difficulties in internally cueing their movements. Patients with Tourette’s syndrome may also require more time to plan and programme each next submovement, and under such circumstances may require external visual cues to direct attention effectively to given targets.

Research to date has focused primarily on the genetics, neuropathology, and clinical

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assessment of the disorder via the use of clinical neuropsychological tests. In consequence, there has been very little systematic experimental research to disclose the underlying motor deficit in voluntary movement in Tourette’s syndrome. This study therefore aimed to quantify the efficiency and smoothness of voluntary movement in Tourette’s syndrome via the use of a graphics tablet which permits analysis of movement profiles. Unlike our previous study,17 which involved discrete forced choice responding, this task required subjects to conduct more ballistic movements towards various predetermined circular targets. Previous studies using similar techniques have focused on other movement disorders, such as Parkinson’s disease18 and Huntington’s disease.17

In particular, we aimed to ascertain whether a concurrent task would differentially affect the movement kinematics of patients with Tourette’s syndrome. It is well established that patients with Parkinson’s disease are impaired in performing two different tasks simultaneously18–21; it is unclear, however, whether there is a corresponding deficit in Tourette’s syndrome. Brown et al.22 attempted to ascertain whether this deficit was specific to Parkinson’s disease, or whether it was evident in other patient populations: those with Huntington’s disease and those with cerebellar disease. The authors found that when combining two manual movements together (tapping and placing pegs), patients with Parkinson’s disease and cerebellar patients were able to maintain performance on the task requiring visual control of placing pegs, whereas performance on the tapping task significantly worsened. Patients with Huntington’s disease, on the other hand, were significantly less impaired; they were able to tap better when placing pegs than the other two patient groups. Patients with Huntington’s disease were, therefore, less affected by the presence of the concurrent task. In Tourette’s syndrome the pattern of motor performance under concurrent task manipulations remains unclear, although by analogy with Huntington’s disease, another hyperkinetic disorder of the basal ganglia, a concurrent task may not detrimentally affect performance.19 In a study similar to the present one but with patients with Huntington’s disease we found that whereas patients’ movement kinematics were more impaired than controls, their movements in fact became somewhat more efficient with a concurrent task.22

There has been much research on concurrent manual and cognitive performance in normal subjects. Kinsbourne23–25 maintains that each hemisphere has its own limited set of attentional and cognitive resources. Execution of a concurrent task will primarily draw on resources in the hemisphere in which they are represented, leaving fewer resources in that hemisphere for the primary task.

This study adopted a concurrent task design and sought to answer three questions. Firstly, whether patients with Tourette’s syndrome would exhibit abnormalities in the kinematics of goal directed voluntary movements; secondly, whether a concurrent task would differentially affect movement kinematics in Tourette’s syndrome; and thirdly, whether patients with Tourette’s syndrome would exhibit abnormal functional asymmetries compared with their matched controls. Patients with Tourette’s syndrome and their matched controls performed a series of 12 sequential vertical zig zag movements, with both left and right hands (with and without a concurrent task), towards circular targets over various movement extents (long or short strokes), and with various precision requirements (large or small targets). By manipulating movement amplitude and target size we are able to examine differences between kinematic profiles as a function of changes in the spatial constraints of movement sequences.26 Movements were sampled on a digitising tablet17 allowing for precise specification of hand trajectory and velocity profiles. For the concurrent task, subjects were required to mentally rehearse a series of digits while performing the movement and to subsequently recall the digits on movement completion. The primary motor task was also performed independently of the concurrent task. The procedure was identical to that used in our previous study with a group of patients with Huntington’s disease.22

Given the previous findings,10,22 we predicted that the quality movements of patients with Tourette’s syndrome might not differentially worsen in the presence of a concurrent task, and that patients with Tourette’s syndrome might exhibit abnormalities in behavioural asymmetries.

Methods

SUBJECTS

Twelve patients with Tourette’s syndrome, all volunteers recruited from the Victorian Tourette Syndrome Association, and 12 age matched controls with no history of neurological disorder participated. Control subjects were recruited from a healthy population and were matched to patients by sex, age (within 2 years), and short test of mental status (STMS) score.27 All subjects gave their informed consent to participate in the study before testing. There was one woman and 11 men in each group, with a mean age of 30.8 years in each group. All subjects were right handed for writing (a preference measure) and were assessed in accordance with our22–23 standard pegboard procedure (a performance index). This task involved moving a series of 10 pegs between two rows of holes as quickly as possible. After several practice trials this was completed four times, with each hand, both towards and away from the subject. Subjects were considered strongly right handed if they were at least 0.4 seconds faster with their right hand than their left. All subjects had normal or corrected to normal vision. Patients with Tourette’s syndrome were all diagnosed by a psychiatrist and met DSM-III-R diagnostic criteria18 for Tourette’s syndrome with chronic motor and vocal tics, onset before the age of 21 years, and duration of tics of more than one
PROCEDURE

Target sheets were centred on the active surface of the tablet and fixed at each corner with clear adhesive tape. The x and y coordinates for each target centre were specified for the computer by the experimenter, and were stored for subsequent analyses of stroke accuracy. The tablet was centred on the body midline, about 100 mm in front of the subject.

The task was to produce a continuous series of 12 vertical strokes, sequentially moving the pen tip up and down into each target and so producing a vertical zig zag pattern. Subjects began with either their left hand (at the bottom left target, and moving up and then down towards the right), or with their right hand (at the bottom right target, and moving up and then down towards the left). For each target configuration they completed the task with and without a concurrent task. Without the concurrent task, and before each trial, each subject positioned the pen tip inside the target (either bottom left or right). The experimenter called out “ready, set, go,” and on hearing “go” the subject began the movement. The concurrent task consisted of a digit span forward sequence (random selection of numbers 0–9) which was called out by the experimenter before the command to move. Each subject was instructed to mentally rehearse the digit span, repeatedly, while conducting the motor task, and subsequently to recall the digits in the original order on movement completion. A pilot study had determined that for patients with Tourette’s syndrome a digit span of six was the maximum number of digits that patients could accurately recall, itself perhaps indicating in that population abnormal attentional strategies. It was used thereafter for all subjects and conditions and errors were recorded manually by the experimenter. Rather than selecting a span of maximum difficulty for each subject, we adopted the more conservative procedure of employing the same digit span of six for all participants, even though this span might have proved relatively easy for controls, so that we could directly compare error rates between groups in the presence of the motor task. An exactly similar procedure was successfully adopted in our companion study on the effects of a verbal concurrent task on movement kinematics in Huntington’s disease.

<table>
<thead>
<tr>
<th>Tourette’s patients</th>
<th>Controls</th>
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<tbody>
<tr>
<td>Male</td>
<td>11</td>
</tr>
<tr>
<td>Female</td>
<td>1</td>
</tr>
<tr>
<td>Mean (SD) age (y)</td>
<td>30.8 (14)</td>
</tr>
<tr>
<td>Mean (SD) duration of illness (y)</td>
<td>8.8 (11.3)</td>
</tr>
<tr>
<td>Mean (SD) MAS score</td>
<td>11.1 (5.3)</td>
</tr>
<tr>
<td>Mean (SD) STMS score</td>
<td>33.8 (2.3)</td>
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</table>

MAS = mood assessment scale; STMS = short test of mental status.

There were four different types of target configurations, each presented on A4 size transparent plastic sheets to reduce friction. There were 13 targets in each configuration; these were depicted as unfilled black circles with a line thickness of 0.5 mm. The targets were arranged horizontally with six targets on the top and seven targets on the bottom section of each transparent sheet. This allowed for 12 vertical zig zag movements to be executed. The horizontal separation between the centre of each target was held constant at 30 mm. The diameter of each of the circles was either 10 mm (small targets) or 20 mm (large targets), and the distance between the centre of each target in the vertical axis was either 62.5 mm (short strokes) or 125 mm (long strokes). Figure 1 shows the target configurations.

Figure 1  Illustrations for each of the four target configurations.
In dual task paradigms there may be a trade-off in performance between the two concurrent tasks. To avoid possible concentration on one task at the expense of the other, subjects were instructed to allocate equal emphasis to both tasks, and to perform the movements as quickly and as smoothly as possible without compromising accuracy, aiming for the centre of each target. Trials in which strokes were omitted were repeated. Very few trials were repeated under these circumstances. There were two practice trials at the beginning of each new target configuration and task type (without concurrent task); subsequently, two error free trials were obtained. In total there were 32 trials, 16 with and 16 without the concurrent task. Hand (left hand beginning on left, or right hand beginning on right), target configuration (small targets—short strokes, small targets—large strokes, large targets—small strokes, large targets—large strokes), and task type (without concurrent task, with concurrent task) for each target configuration were counterbalanced across subjects.

DATA ANALYSES
Horizontal and vertical vector components were obtained for each movement, although only the vertical components were analysed as movements were primarily along the vertical axis. The data were filtered (low pass, 10 Hz cut off) using a recursive, dual pass, second order Butterworth filter. Secondly, displacement data were differentiated using a nine point central finite differences algorithm to obtain velocity and acceleration functions for each trial. Automatic algorithms were then used to calculate movement accuracy and to determine kinematic features of the movement such as duration, peak velocity, and force inefficiency functions.

MEASURES
Displacement dimensions
Accuracy of stroke end points, in relation to the target centre, was calculated (in mm) for each target and then averaged. The accuracy measure represented the average distance (in mm) from the stroke end point to the target centre, independent of direction. This was determined to ensure consistency in the accuracy of end point strokes made by the two subject groups. Movement time reflected the average time (in ms) per stroke, averaged over the entire trial (12 strokes).

Stroke kinematics
Measures of stroke kinematics such as peak velocity and force inefficiency were also calculated. Peak velocity (mm/s) represented the maximum velocity attained over the entire trial (12 strokes). The force inefficiency index was calculated by dividing the number of zero crossings in the accelerative function by the number of zero crossings in the velocity function. This measure therefore represented the average number of changes from acceleration to deceleration per submovement; thus the greater the value of the inefficiency index the more inefficient the movement. All measures were averaged over two trials per target configuration.

RESULTS
Subject means for each of the measures were submitted to separate five way analyses of variance (ANOVAs) with non-repeated measures of group (Tourette’s syndrome, controls), and four repeated measures—namely, task (without concurrent, with concurrent), stroke length (long, short), target size (large, small), and hand (left, right), with repeated measures on the last four factors.

To correct for a possible violation of the assumption of normality, a stringent level of 0.025 was adopted for the data presented below.

ANALYSES OF DISPLACEMENT DATA
Movement time
Movement time analysis disclosed significant main effects of stroke length \(F(1,22)=67.63, P<0.001\), target size \(F(1,22)=60.69, P<0.001\), and hand \(F(1,22)=6.24, P<0.05\). There was also a significant group by stroke length by hand interaction \(F(1,22)=13.06, P<0.01\) (fig 2). Stroke length differentiated patients with Tourette’s syndrome from controls; patients with Tourette’s syndrome executed long strokes somewhat faster with the right, compared with the left, hand, whereas only the controls showed the expected right hand superiority with the short more difficult strokes.

Movement accuracy
No main effects or interactions approached significance. Any performance differences between the patients with Tourette’s syndrome and controls are therefore unlikely to be due to any speed-accuracy trade off. All participants were equally accurate in movement end points regardless of target size (large, small) and stroke length (long, short).

KINEMATIC ANALYSIS
Peak velocity
Analysis of peak velocity disclosed significant main effects of stroke length \(F(1,22)=125.98, P<0.001\) and target size \(F(1,22)=21.57, P<0.001\).
Controls (%) 0 0 0 0 8 4 0 0
Tourette's (%) 13 8 8 8 21 13 0 8

<table>
<thead>
<tr>
<th></th>
<th>Large targets</th>
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<th>Small targets</th>
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<tbody>
<tr>
<td></td>
<td>Long strokes</td>
<td>Short strokes</td>
<td>Long strokes</td>
<td>Short strokes</td>
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<tr>
<td>LH</td>
<td>RH</td>
<td>LH</td>
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<td>LH</td>
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<tr>
<td>Tourette's (%)</td>
<td>13</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Controls (%)</td>
<td>0</td>
<td>0</td>
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LH = left hand; RH = right hand.

There was also a significant group by task by hand interaction ($F_{1,22} = 9.46$, $P<0.01$) (fig 4). An overall superiority of the patients with Tourette's syndrome was modified by an apparent interaction between hand and task; thus the addition of a concurrent task seemed to make the right hand more efficient for the patients with Tourette's syndrome, whereas for controls such an added verbal concurrent task improved the efficiency of the left hand relative to the right.

**DIGIT SPAN RECALL ERROR RATE**

Overall, patients with Tourette's syndrome made more digit span recall errors than controls (table 2). More errors were made by patients when executing small targets-long strokes (21%) with the left hand. Despite the fact that patients with Tourette's syndrome were faster in overall movement times and peak velocities with the small, precise targets, the overall error rate between large (37%) and small (42%) targets was virtually identical. Numbers overall were insufficient for statistical analysis.

**DEPRESSION OR MEDICATION STATUS**

To determine whether depression or medication status affected the pattern of results on the patients' data, patients with Tourette's syndrome were categorised into either depressed or non-depressed or medicated or unmedicated; Yesavage et al. state that the cut off for depression should be 10 and above out of a maximum of 30. Seven out of 12 patients were depressed (five non-depressed), and five were medicated (seven unmedicated). A repeated measures ANOVA was conducted for each patient group according to their depression or medication status, and only for the force inefficiency index which had yielded the most interesting results (above). For the depressed or non-depressed, and the medicated or unmedicated Tourette's syndrome groups, there were significant main effects of stroke length ($F_{1,10} = 12.25$, $P<0.01$ and $F_{1,10} = 11.28$, $P<0.01$ respectively) and of target size ($F_{1,10} = 15.84$, $P<0.01$ and $F_{1,10} = 13.91$, $P<0.01$ respectively); there were no main effects or interactions involving group. These results clearly indicate, given the absence of significant group effects, that neither depression nor medication status affected the pattern of results in the Tourette's syndrome data.

**Discussion**

This experiment sought to assess the efficiency of voluntary movement and to ascertain whether a concurrent task would differentially affect movement kinematics in Tourette's syndrome. The findings can be summarised as follows: with short, precise strokes, controls showed the predicted right hand superiority in movement time more strongly than patients with Tourette's syndrome, who showed greater hand asymmetry instead with such short strokes. The practised right hand of controls was less force efficient with short strokes, whereas in patients with Tourette's syndrome, both hands were equally force efficient whatever the strokes' length; both hands in patients with Tourette's syndrome showed a pattern of performance similar in profile to, but slightly better than, that of the left hand in controls.
the left hand. (The right hand in controls was more subject to movement changes in acceleration and deceleration profiles and in this way may be seen to be less force efficient with the long strokes.) Either hand of patients with Tourette’s syndrome was equally force efficient, irrespective of stroke length, with an overall performance profile similar to but better than that of the controls’ left hand. The overall superior force efficiency of patients with Tourette’s syndrome was modified by the effects of hand and verbal concurrent task; the second seemed to increase the force efficiency of the right hand in patients with Tourette’s syndrome and that of the left hand in controls. Our findings clearly add to the growing literature on anomalous lateralisation in Tourette’s syndrome. Moreover, neither depression nor medication status had a differential effect on the Tourette’s syndrome pattern of results. This finding has been reported in our previous studies not only with Tourette’s syndrome, but also with Huntington’s disease and Parkinson’s disease.

It has been previously determined that in rapid movement tasks, such as aiming, the right hand tends to show superiorities over the left. The right hand/ left hemisphere system has been reported as superior in movement execution; this tends to be more pronounced in tasks requiring more difficult movements, or when advance information is maximal. In this experiment, however, movements were not particularly difficult, and there were no manipulations of advance information. Carson claims that observable asymmetries in a given task may appear as a vector representing different contributions from the two specialised hemispheres. With a verbal concurrent task (which has greater left hemispheric involvement), we may expect a right hand decrement in manual performance. Yazgan et al administered a verbal concurrent task to a group of patients with Tourette’s syndrome and controls while they completed a motor task with either hand. The authors found that the interfering impact was on the right hand for controls; patients with Tourette’s syndrome showed reductions in the normally occurring asymmetries—that is, there was no significant difference in performance between left and right hands. On the contrary, our results could be interpreted as showing that the verbal concurrent task slightly improved the force efficiency of the right hand in patients with Tourette’s syndrome and the left hand in controls. Note, however, that Yazgan et al in their experiment only assessed movement time as their performance measure. Despite this conservative procedure, patients’ motor performance was still superior to that of controls according to some variables. Although all subjects were instructed to allocate equal attention to both tasks, it is nevertheless possible that patients still chose to attend more to the motor tasks. If so, this would itself be a finding of some interest.

In a discrete serial button pressing task that involved sequential forced choice responding, we have shown that compared with controls patients with Tourette’s syndrome were particularly disadvantaged in movement execution with high reductions in advance information. Patients with Tourette’s syndrome may be particularly impaired in situations in which rapid serial processing decisions are imposed, especially under the influence of cue manipulations. In discrete ballistic tasks, however, such as aiming at targets, movements may become...
more automated as decisions where to move are minimised due to the preselected nature of the targets, and the availability of ongoing visual guidance; patients with Tourette’s syndrome may benefit under such circumstances. The basal ganglia are conceived as performing a filter function, selecting requisite movement synergies, and selecting out, or inhibiting, unwanted response sequences. If this system is affected, as in Tourette’s syndrome, in consequence unwanted "tic-like" behaviours may be inappropriately released, and in particular visually guided movements may be performed in an abnormally rapid fashion. Such an account may explain not only the present performance superiority in Tourette’s syndrome, but also the hyperactive, exaggerated, and explosive nature of the disorder. Indeed, it may be the case that the Tourette’s syndrome gene or genes, in low doses, may even facilitate behaviour such as that tested here, and so may persist in the genome. However, higher doses, or penetrance, may be associated with clinical symptoms that so characterise the disorder. Sacks describes “Witty Tickey Ray” who was a remarkable musician: “...a weekend jazz drummer of real virtuosity, famous for his sudden and wild extemporisations, which would instantly arise from a tico or a compulsive hitting of a drum and would instantly be made the nucleus of a wild and wonderful improvisation, so that the “sudden intruder” would be turned to a brilliant advantage” (p 94). Sacks also describes a man of remarkable intellect who found his disorder to be advantageous in some respects. Alternatively, the Tourette’s syndrome gene or genes may alter strategies in how attention is deployed. There are two possibilities. Firstly, patients may have directed more attention toward the motor task and consequently made more errors on the digit span task. A second alternative is that patients directed less attention to the motor task because the digit span was more difficult and demanded more attention; the motor task may then have improved, perhaps because it was run at a more automatic level. Clearly, the first hypothesis is the simpler and more consistent with the poor Tourette’s syndrome performance in the digit span task, even with fewer digits to process. Thus patients may attend more to their own movements than to other ongoing activities.

In conclusion, this study has documented that patients with Tourette’s syndrome, compared with controls, are not impaired in the performance of fast, goal directed movements such as aiming at targets. In fact, patients with Tourette’s syndrome performed better than controls in certain respects—that is, they showed improvements in force efficiency with the concurrent task. The reported loss of normal basal ganglia asymmetries in Tourette’s syndrome may help to explain the altered functional asymmetries between the two groups.

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