

A Method to Assess Hand Motor Blocks in Parkinson's Disease with Digitizing Tablet

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The non-volitional sudden discontinuation of motor activity, called motor block (MB) or freezing is most commonly associated with Parkinson's disease (PD). MB extends beyond the classical manifestations of PD: akinesia, bradykinesia, rigidity, tremor, and postural instability. MB has been observed and quantified in internally cued repetitive movements such as gait, speech, handwriting, and manual tapping tasks as a distinct feature of PD. We present a simple measurement system for objective evaluation of MB during point-to-point hand movements in patients with PD. Hand trajectories were evaluated in eight PD patients based on values obtained from a digitizing tablet (DT) score. 50 trials per day were recorded in seven consecutive working days. Subjects were instructed to consciously prepare and self-initiate movements between arbitrarily fixed starting and target points without lifting a wireless magnetic mouse. MB was identified as the time interval during movement with no change in coordinates. We analyzed three kinematic parameters: duration, start and number of MBs. If MBs were documented, the DT score was 1, if not, 0. Results were then compared with the ratings of the question in motor section related to freezing of hands from the Unified Parkinson's Disease Rating Scale (UPDRS). For all patients, DT score was in agreement with the UPDRS. Present results indicate that DT is useful for assessing MBs during volitional planar hand movement. This low-cost instrument may be included in a clinical test battery because of short testing time and trouble-free preparation of patient. ——— Parkinson's disease; motor block; freezing; digitizing tablet; assessment.

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Freezing refers to transient periods in which the voluntary motor activity being attempted by an individual is paused (e.g., Giladi et al. 1992; Ringendahl et al. 1997; Darmon et al. 1999; Hausdorff et al. 2003; Jankovic 2008). It is a sudden, unplanned state of immobility that appears to arise from deficits in initiating, simultaneously and sequentially executing movements, correcting

inappropriate movements, or in planning movements (Ringendahl et al. 1997). In the literature the terms *freezing*, *MB - motor blocks* (Giladi et al. 1992; Jankovic 2008), *motor blockades* (Darmon et al. 1999), or *MMB - manual motor blocks* (Ziv et al. 1999) are used to define the same impairment. Freezing is a poorly understood feature of a number of conditions, yet it is

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most frequently associated with Parkinson's Disease (PD).

Freezing extends the classical manifestations of PD (akinesia, bradykinesia, rigidity, tremor, and postural instability). Giladi et al. proposed that, in PD, MBs are the abnormal retrieval or execution of complex motor tasks that can occur as a result of disease progression or as short or long-term side effects of levodopa treatment. Freezing is mostly linked to gait (freezing of gait - FOG) (Giladi et al. 1992, 2001, 1997; Lamberti et al. 1997; Hausdorff et al. 2003), but it is also associated with other rhythmic and internally cued repetitive movements (Lamberti et al. 1997) such as speech (Ackermann et al. 1993), handwriting (Eichhorn et al. 1996), and tapping (Nagasaki et al. 1988; Ziv et al. 1999; Yahalom et al. 2004). One mode of freezing may be correlated to another (Ziv et al. 1999). When associated with gait, it is recognized as start hesitation (gait initiation), blocking on turning and blocking in narrow spaces (Giladi et al. 2001).

Various methods of measuring the classical symptoms of PD in an objective and quantitative way have been proposed (Ghika et al. 1993; Jobbagy et al. 1998), specifically for tapping test (Ziv et al. 1999; Yahalom et al. 2004), the quantification of rigidity (Patrick et al. 2001), handwriting (Eichhorn et al. 1996), to evaluate FOG (Han et al. 2003; Moore et al. 2008), or to assess MBs in hand movements (Popovic et al. 2002).

Ghika et al. (1993) designed portable system based upon a PC to measure tremor, bradykinesia, and muscle tone. Tremor was detected by accelerometers, bradykinesia was detected using a panel that detects release and depression of switches in response to auditory and visual signals, and strapping the upper extremity to a lightweight low-friction cradle and then passively moving the cradle with the instrumented handle detected tone at the elbow. Eichhorn et al. (1996) used a computational analysis of open loop handwriting and a clinical rating scale for monitoring the effect of apomorphine. PD patients were instructed to write fluently concentric circles while movements were recorded using a digitized tablet. Two parameters were computed, the mean peak velocity

and the acceleration. Clinical rating was performed according to UPDRS part III and compared with kinematic derivations. The authors concluded that the computer-assisted analysis of automated handwritings could be used as a fast objective method for quantifying dopaminergic effect on the kinematics of handwriting. Jobbagy et al. (1998) described a measurement technique based on the Precision Motion Analyzer (PRIMAS) that can be used to diagnose PD. PRIMAS was suggested as a screening test to objectively measure the progress of the disease and/or the efficacy of the therapy. Ziv et al. (1999) developed method for computerized quantitative measurements of the frequency, duration and temporal profile of MMBs during performance of manual tapping test. Patrick et al. (2001) designed a device to quantify rigidity at the elbow and the wrist. The method quantifies the clinical examination with sensors that monitor forces and angular displacements imposed by clinician onto the limb segment distal to the joint being evaluated. They concluded that mechanical impedance was nonlinearly related to UPDRS (Fahn and Elton 1987) ratings of rigidity at the elbow and wrist. Popovic et al. (2002) examined existence of motor blocks in PD patients during volitional point-to-point hand movement based on computational analysis by the use of a specially developed computational algorithm that was applied to a collection of kinematic parameters. Significant differences in kinematic features were found among groups of PD patients having MBs, PD patients not experiencing MBs and healthy control. Han et al. (2003) developed system to monitor walking where the Unconstrained Monitoring System (UAMS) measures the body's acceleration with 3-axis accelerometers while the movement was recorded by camcorders. Using frequency analysis, FOG episodes were detected and separated from normal walking. Yahalom et al. (2004) used a digitized switchboard to classify PD patients into tremor predominant, freezing predominant, akinetic-rigid and unclassified groups. Moore et al. (2008) developed an ambulatory system for monitoring of FOG where an ankle-mounted sensor array transmitted vertical linear acceleration

wirelessly to a pocket PC. A freeze index (FI) was defined as the power in the freeze band divided by the power in the locomotor band. The threshold was chosen such that FI values above this limit were designated as FOG.

In the present study we used a drawing tablet to record participants' volitional planar movements. The non-volitional sudden braking of hand movement was identified as MB and its kinematic parameters were calculated. Patients were clinically evaluated according to UPDRS motor part. Finally, the rating of the question related to freezing of hands from UPDRS was compared to the results of the kinematic analyses. Assessment of MBs with DT was illustrated by summarizing the results of eight PD patients out of which three were experiencing motor blocks.

METHODS

Subjects

Eight PD patients were assessed for the presence of episodic hand movement disturbances at the Institute of Neurology Clinical Center of Serbia (INCCS). The study was performed in accordance with the ethical standards of the Declaration of Helsinki. Institutional ethics committee approval was obtained and participants gave informed consent prior to inclusion in the experiment. The clinical characteristics of this group are presented in Table 1. During the testing period, patients were on optimal drug therapy. Testing was always at the same time.

Motor performance

Subjects were seated at a writing desk where a digitizing tablet was placed with the cordless mouse. The

subjects were asked to find their most comfortable position and if necessary, we adjusted the position of the digitizing board. Subjects were instructed to move their hand between arbitrarily fixed starting and target points without lifting a mouse. The two markers were placed at the starting and target positions on the tablet, as shown in Fig. 1. Only the evaluator monitored the computer screen that was out of the patients' visual field. Instructions were standardized, and contained the following command: "Move your hand in a normal fluent manner between the two markers". Subjects were always reminded that every movement should be consciously prepared and self-initiated. 50 trials of point-to-point movements

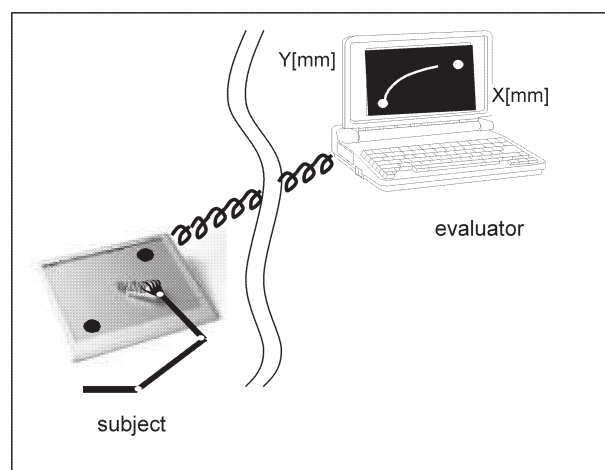


Fig. 1. Sketch of the experimental setup.

Subject was seated at the desk with the digitizing board. The task was to move the hand from the starting to the target point. A wireless magnetic mouse that recorded XY coordinates was used during the motion. Data was transferred to the computer and only the evaluator monitored the movement on the screen.

TABLE 1. Patient's demographics.

Group	PD patients
Number/gender	8 / 5f+3m
Age (Mean, range in years)	53,4 (43-75)
Duration of disease (Mean, range in years)	5,28 (4,1-7,3)
Duration of therapy (Mean, range in years)	4,3 (3-10)
Mean H&Y ¹ stage on/off (range)	2,5/3 (1-3/1,5-5.5)
Mean UPDRS ² III score on/off (range)	27,3/38,2 (12-45/25-72)
Mean score for question #24 UPDRS III on/off (range)	1,75/2.125 (0-4/0-5)

¹H&Y, Hoehn & Yahr Clinical (Hoehn and Yahr 2001) stage of PD

²UPDRS, Unified Parkinson's Disease Scale (Fahn and Elton 1987)

were performed on seven consecutive working days. On average it takes about 10 minutes to prepare the patient for the first session. Patients are instructed how to use the system to perform the task. Each participant exercise several trials to become familiar with the testing method. Testing sessions take several minutes in average, but in cases with motor blocks they can last longer.

Apparatus

Hand movements were recorded using a digitizing board (Drawing Board III, 305 × 457 mm, GTCO CalComp Inc, cordless 4-button mouse, 14555 N 82nd St, Scottsdale, AZ 85260) with a sampling frequency of 100 Hz. The resolution was 1000 lines/cm and accuracy 0.25 mm in horizontal (X) and vertical (Y) directions.

Recordings and data processing

The positional data from mouse cursor was acquired using a custom made Virtual Instrument (National Instruments). The data consisting of XY coordinates was transmitted to a personal computer.

For the recording of hand trajectories we used an interactive custom made program written in LabView 6 (National Instruments, 11500 N Mopac Expway Austin, TX 78759-3504). Basic processing and detailed analysis was performed with the MatLab 6 (The MathWorks Inc, 3Apple Hill Dr, Natick, MA 0176-2098) software package. Each movement trial was extracted and smoothed by using the 4th order Butterworth filter at 20 Hz. The analysis was focused on kinematic parameters and configured to generate a graphical representation of the kinematic data and numerical values. A computer screen was only used off-line to allow patient and evaluator to review performed movement.

Movement analysis

The start and end of each trial was determined with a preset threshold that was 5% from trial maximal velocity. We defined three parameters to analyze hand movements: the number of motor blocks (n), the duration of a motor block (d), and start or onset of motor blocks(s).

Motor block duration (d) was defined as the time interval during movement when no change in X and Y occurred. It is expressed in seconds. Normalization was done by dividing d with movement duration (T) and expressing in percentage $d_{\%}$.

If one or more MBs occurred during movement, then the duration of movement was subsequently decomposed ($T_1, d_1, T_{12}, d_2, T_{23}, d_3, \dots, d_i, T_{ij}, d_j, \dots, T_{n-1,n}, d_n, T_n$),

where T_{ij} was the time between MBs i and j lasting d_i and d_j respectively. The total duration of the motor blocks (D) was calculated as the sum of all isolated MBs.

Entire motor block duration (D) was normalized by dividing it with the movement duration T, and expressed in percentage ($D_{\%}$).

The onset of motor block (s) was determined as the moment when motor block appears. It was normalized by dividing with T and expressed in the percentage ($s_{\%}$).

DT score and its validation

We defined DT score as follows: if motor blocks existed, $DT = 1$, otherwise $DT = 0$. The results of DT were then compared to the standardized clinical test, in particular, with the score of question #24, part III of UPDRS scale. We considered subjects as hand freezing predominant if they scored 2 or higher on the freezing of hand question #24 in the UPDRS part III (Yahalom et al. 2004; Jankovic et al. 1990). We propose that assessment with DT was validated with a clinical rating if one of two conditions existed:

- ▶ $DT=1$ and score for q#24 ≥ 2 (freezing predominant), or
- ▶ $DT=0$ and score for q#24 < 2 (non-freezing).

RESULTS

All recorded hand trajectories were plotted. Fig. 2. shows two representative examples from patient #7 not experiencing freezing and patient #4 experiencing freezing (a). The bottom panel represents the time course of XY coordinates from the above hand trajectories (b). A plateau-like pattern was observed on a record for patient #4 and annotated with MB.

We analyzed all the recorded trials. If MB existed, its onset was annotated with an arrow and a letter "s". The movement duration of the trial shown in Fig. 3.(a) was $T = 630$ ms. Duration of MB (56,7 ms) was normalized $d_{\%} = 9\%$, as well as the onset of MB (at 242 ms) was normalized $s_{\%} = 38\%$. For movements with more motor blocks ($n > 1$), the computation was extended. Analysis of the trial presented in Fig. 3.(b), lasting $T = 490$ ms, revealed two motor blocks: MB_1 and MB_2 . Their onset was marked with s_1 and s_2 . Blocks started at instants $s_{1\%} = 5,7\%$ and $s_{2\%} = 18,2\%$. The total duration of the motor blocks was $D = 74$ ms, or $D_{\%} = 15\%$.

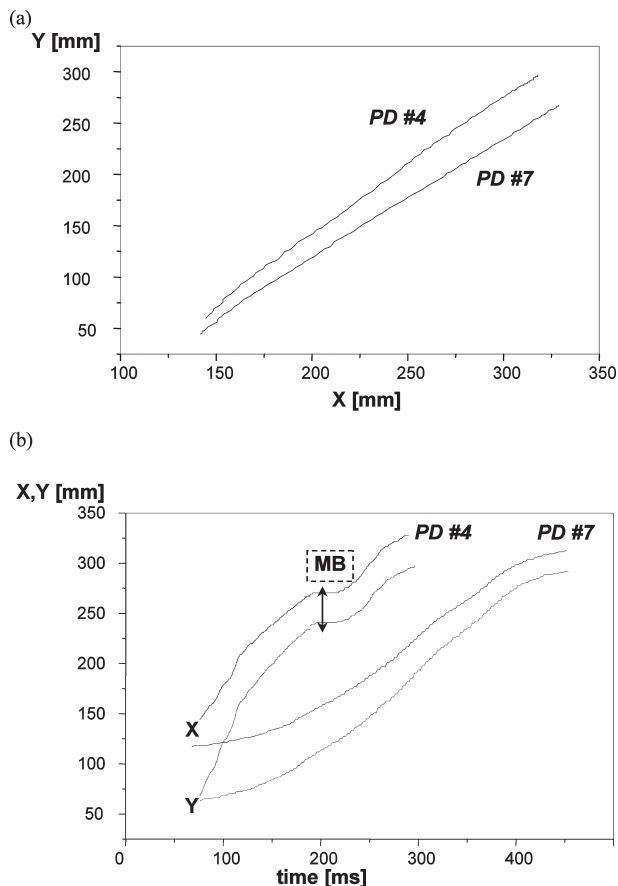


Fig. 2. Output signals from Parkinson's Disease patients.
 (a) XY plots of recorded hand movements for: PD#4 for 23rd trial on 2nd day and PD#7 for 26th trial on 4th day.
 (b) Time course of horizontal – X (tick line) and vertical – Y (dotted line) components for XY plots in (a). MB is for motor block. Raw data is shown.

Summarized results of the evaluation of patient #4 are shown in Fig. 4. The distribution (a) of all motor blocks ($n = 182$) during recording shows that MBs occurred in a little over the half of all trials (52%). Appearance of one MB was the most frequent. It was recorded in around one fifth of trials, but there were some trials where MB frequency was up to seven. Eighty nine percent of all MBs lasted between 0 and 15% of full movement duration (b), out of which little over a half (53.3%) lasted between 5-10%. There was no a single MB that lasted longer than 25% of the duration of the movement. The incidence of MBs

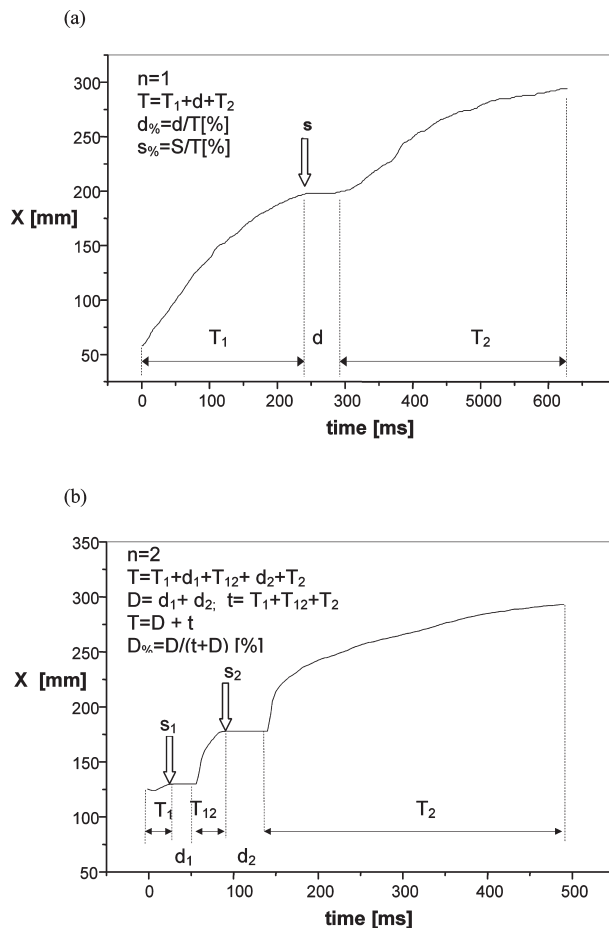


Fig. 3. Detailed presentation of motor blocks (MB) during hand movement in Parkinson's Disease patients.
 (a) Example with one MB ($n = 1$). Duration of movement was separated into three consecutive periods: before motor block (T_1), during motor block (d), and after the motor block (T_2). Motor block onset was marked with s . The duration (d) and start (s) of motor block are expressed as a percentage of the duration of the entire movement and marked with $d\%$ and $s\%$, respectively. Processed data for PD patient #4, for 15th trial on 5th day is shown. Numerical values: $d\% = 9\%$ and $s\% = 40\%$.
 (b) Example with two MBs ($n=2$). Duration of movement time was extensively separated: T_{12} is for hand movement between blocks MB₁ and MB₂. MB₁ and MB₂ started at s_1 and s_2 . Processed data for patient #4, for 41st trial on 1st day is shown. Numerical values: $d_{1\%} = 7\%$, $d_{2\%} = 11\%$, $s_{1\%} = 5.7\%$, and $s_{2\%} = 18.2\%$.

showed an increasing trend towards the end of movement (c). The majority of motor blocks occurred during the second half of the movements (81%). Nearly one half of motor blocks occurred during the last quarter of movement (approaching target point). No variables were consistently found over the course of seven days.

We evaluated 2800 trials (8 patients \times 50 trials \times 7 days) with this method. Motor block periods were found in 12 percent (336/2800) of all recorded trials. All identified motor blocks belonged to three patients. Their analysis showed similar distribution of MB parameters among

patients, a decreasing trend of the distribution of the number of MBs (Fig. 4. a), a bell-shaped distribution of the duration of MBs (Fig. 4. b) and an increasing trend towards the end-point for the distribution of the onset of MBs (Fig. 4. c).

In summary, for the three patients with DT = 1, UPDRS score on question #24 was ≥ 2 (see Table 2.). The remaining five patients had UPDRS score < 2 on question #24 and for them we did not record any MB on any of the recording days (DT = 0). The correlation between DT results and the UPDRS score for question #24 was statistically significant ($p < 0,05$).

DISCUSSION

A great deal of attention has been recently focused on freezing in repetitive movements like gait (FOG) and to a lesser extent, speech. To our knowledge, this study is the first report in a scientific journal written in English where motionless periods were isolated from goal-directed movement (point-to-point) in PD patients.

Based on the method proposed we demonstrated that the characteristic silent periods observed in hand trajectories during volitional point-to-point movement performed by PD patients could be linked to the score on the question related to freezing of hands in motor part of UPDRS. For all tested patients, the results of DT were in agree-

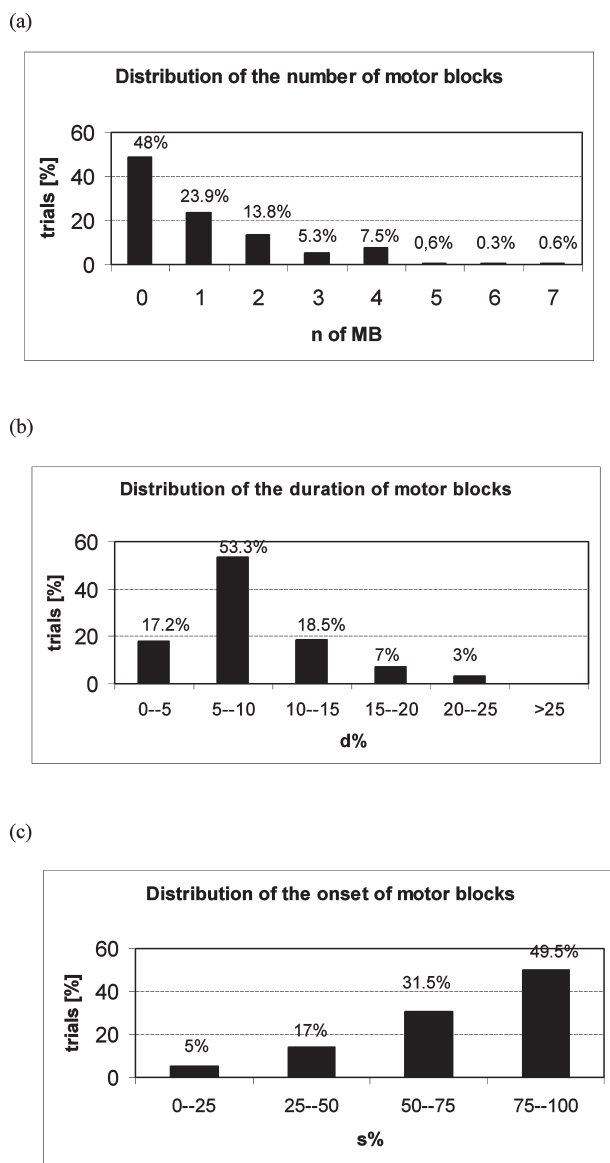


Fig. 4. Summary results of the assessment of motor blocks in PD patient #4.

(a) The distribution of the number of motor blocks ($n = 0-7$). During 48% of the trials no motor block was observed ($n = 0$), and during the rest of trials (52%) there were one ($n = 1$) to seven motor blocks ($n \leq 7$).

(b) The distribution of the duration of motor blocks ($d_{\%}$ is divided in steps of 5% duration). 89% of the motor blocks lasted between 0-15% of the full movement duration. The majority (53,3%) was in the range of 5-10%.

(c) The distribution of the onset of motor blocks ($s_{\%}$ is divided in steps of 25% length). Nearly half of all motor blocks occurred during the last quarter of the movement (75-100%) and close to 30 percent during the third quarter of the movement (50-75%).

TABLE 2. Relation between DT and clinical scores for motor blocks. Number of trials having motor blocks (MBs) for each patient (first column), drawing tablet (DT) score (second column) and score on UPDRS, part III, question #24 (third column). Summary results for all Parkinson's Disease patients are shown.

PD patient	Number of trials with MBs (in percentage)	DT score	UPDRS, part III #24 question ¹
1	0	0	1 (< 2)
2	85 (24%)	1	3 (≥ 2)
3	0	0	1 (< 2)
4	182 (52%)	1	4 (≥ 2)
5	0	0	1 (< 2)
6	0	0	1 (< 2)
7	0	0	1 (< 2)
8	69 (19%)	1	2 (≥ 2)

¹ Freezing dominance (≥ 2)

ment with the score of clinical rating with UPDRS scale, motor part, question #24 (≥ 2, freezing predominant) (Table 2). Therefore, we suggested that these motionless periods were the result of sudden involuntary paused motor activities that were manifested as motor blocks.

With respect to gait, patients commonly describe episodes of freezing (FOG) as a feeling that their feet "are glued to the ground". These sudden and transient difficulties occur at the beginning of (start hesitation) or during walking (steady-state walking, on turning, in narrowing spaces such as entering doorways). In the plan of hand point-to-point movement the end-point may be analyzed as analogous to the situation of the aforementioned narrowing of space. We also observed hesitations at the initiation of movement, as the condition of evaluated task was that the movement was self-initiated. In the condition where start trigger is mandatory we should be able to analyze if hesitation exists.

There is considerable evidence suggesting that basal ganglia (BG) plays two important roles in the performance of learned (repetitive) automatic movement sequences. The first is to match and maintain the amplitude of a cortically selected movement plan (motor set), and the second is to run each component of the plan in a timely manner (motor cue production). Malfunctions in PD

results in a motor set mismatch between the cortically selected step size and that maintained by the BG. Defective cue production causes progressive slowing in a long sequence of movements. It has been suggested that when the two deficits are superimposed on each other, and if either or both is severe, festination (progressively shortening steps) and motor blocks (FOG) may result (Iansek et al. 2006). In goal-directed movements (point-to-point) we suggest that appearance of motor blocks may be explained as the consequence of primarily defective motor plan by the BG.

In this study we analyzed hand movements in a frequently used part of the working space (horizontal plane, front side). Other parts of working space can also be evaluated. Speed of performance was not stressed, but we did measure the time taken to complete the task. The administering time was not an issue in this study, however other timing schedules can be adopted. Correlations with other classical symptoms of Parkinson's disease, as well with other types of freezing and their relation to drug therapy can also be evaluated. This methodology may be adapted to evaluating conditions such as different strategies for overcoming hand freezing, path with obstacles, tracking line instead of connecting two points, dual-task, or movements initiated with triggers instead of self-initiated movements. The

technical system may also be automated in order to produce online results.

CONCLUSION

We were able to demonstrate that the digitizing tablet can be used to record sudden non-volitional discontinuations during volitional planar movements in a group of Parkinson's Disease patients. We speculated that these silent periods were freezing episodes (motor blocks). The results were validated with the standardized clinical test, score on question #24, part III of UPDRS scale relating to freezing of hands.

We suggest that digitizing tablet can be used in clinical settings to assist evaluation of PD patients for upper-extremities during the course of therapy and progression of illness because of the simplicity of the method, short testing time, low cost and trouble-free preparation of patient.

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