Home-Based Monitoring and Assessment of Parkinson's Disease

L. Cunningham, S. Mason, C. Nugent, G. Moore, D. Finlay, and D. Craig

***Abstract*—As a clinically complex neurodegenerative disease, Parkinson's disease (PD) requires regular assessment and close monitoring. In our current study, we have developed a home-based tool designed to monitor and assess peripheral motor symptoms. An evaluation of the tool was carried out over a period of ten weeks on ten people with idiopathic PD. Participants were asked to use the tool twice daily over four days, once when their medication was working at its best ("on" state) and once when it had worn off ("off" state). Results showed the ability of the data collected to distinguish the "on" and "off" state and also demonstrated statistically significant differences in timed assessments. It is anticipated that this tool could be used in the home environment as an early alert to a change in clinical condition or to monitor the effects of changes in prescribed medications used to manage PD.**

***Index Terms*—Computer-based assessment, motor difficulties, Parkinson's disease (PD), remote monitoring.**

I. Introduction

PARKINSON'S disease (PD) is a complex neurodegenerative disease requiring close monitoring and regular assessment. Persons with PD may require frequent and time-consuming visits to specialist centers for assessment and monitoring [1]. Although the main features of PD are motor related, and therefore, impact considerably on daily life, many people with the disease suggest features that are not motor related can affect quality of life more so than the motor related features [2]. Home-based monitoring of PD is a laudable aim that has the potential to reduce the necessity to attend frequent consultations with specialist personnel in addition to offering potentially more precise and continuous monitoring paradigms sensitively assessing disease progression and medication effects [3]. The current methods of assessment and monitoring of PD are arguably subjective. Therefore, a home-based computer monitoring tool could help make the process more objective by providing the clinician with some quantitative feedback on a person's condition.

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II. Parkinson's Disease

As the second most common neurological condition, PD affects a large cohort of the worldwide population [4]. It is estimated that worldwide 4 million people are living with PD [5]. The disease affects a part of the brain known as the "substantia nigra," which controls movement in the body. Essentially there is a lack of dopamine (neurotransmitter) in the brain when PD is present. It is a progressive disease that usually affects people over 50 years of age, however, younger people can also be diagnosed with the disease and this is known as "early onset PD" [4], [6]. There are a wide range of features associated with the disease making diagnosis difficult. It is thought that PD can only be definitively diagnosed at postmortem that further highlights the complexities of diagnosis [7].

A. Features of PD

Of the vast number of features relating to PD there are four main features that clinicians look for during patient assessment. These features are Bradykinesia/akinesia, tremor, rigidity, and posture and walking difficulties. In order for a diagnosis to be made Bradykinesia needs to be present along with at least one of the other three features. Details relating to the main features of PD are presented in Table I.

Aside from the main features presented in Table I, there are many other less-common features of PD such as sleep disturbances, cognitive problems, and sometimes even dementia [6]. As previously mentioned, these features can be equally debilitating as the main features and can impact greatly upon quality of life. These features of PD can be more pronounced at certain times due to a number of factors such as the medication they are on, time of day, how tired they are etc. People with PD are considered to have two states, "on" and "off". The "on" state means that a person's medication is working at its best, which often results in more ease of movement. In contrast the "off" state means that their medication has worn off and movements can often be more difficult.

III. Relevant Work in the Area

The concept of monitoring and assessing chronic disease within the home is one, which is currently being widely explored [8]–[13]. Several studies have been carried out examining the remote monitoring of people with PD in particular [10], [11]. One such study looked at the feasibility of a home-based motor impairment testing device [10]. The device used was a computer-based testing device containing apparatus to carry out a series of tests/tasks. The device included: a two-key keyboard for the finger-tapping test, two buttons placed 173 mm apart to test

TABLE I
SUMMARY OF THE FOUR MAIN FEATURES OF PD

Feature	Description
Bradykinesia / akinesia	A slowness or loss of spontaneous movement which results in a reduction in independence [4]. Bradykinesia is a slowness of movement and difficulty with initiating and sustaining movement. Akinesia is a complete lack of movement (freezing). An example of Bradykinesia would be if a person with PD gets up from a seated position to walk and has trouble initiating the actual walking motion. Akinesia can be seen when a person is walking along and suddenly is unable to move at all.
Tremor	A trembling in the hands, arms, legs, jaw or face. It often begins in the hand and can affect only one side of the body. It is an uncontrollable movement which has a rhythm (normally 4-6Hz). It has been found that some people with PD tremor see an improvement with intentional movement [4]. Statistics show that 70-90% of people with PD develop tremor [5], [7].
Rigidity	A stiffnesss in some of the limbs and sometimes also in the trunk. Stiffness in the facial muscles can also lead to a lack of facial expression. It can often make tasks which involve a change in position, very difficult to carry out. An example would be difficultly gripping objects. More than 90% of people with PD develop rigidity [5], [7].
Problems with walking and posture	Impaired balance and coordination leading to falls. Postural instability leads to a stooped posture which in turn leads to difficulty with walking. Usually the last feature to appear and can indicate a progression to the advanced stages of PD.

reaction time/movement time and hand tapping testing, an eight-peg pegboard to test complex motor function, a microphone to allow for testing of speech, and a docking station for the wrist worn tremor-assessment equipment. All data collected by the device were sent via the internet to a data repository [10]. The data were then collected from the repository and analyzed. Fifty-two participants took part in the study and were asked to carry out weekly assessments on tremor, bradykinesia, speech, reaction, and movement time and complex motor control [10]. All of the results collected were compared to the Unified PD Rating Scale (UPDRS) motor ratings. The UPDRS is a guide for clinician's while they carry out basic tests on people with PD. The rating scale enables clinicians to give a rating for each feature of PD present in each patient, such as tremor, Bradykinesia, etc. Although the compliance was high for this study and data transmission appeared reliable, it did involve the use of invasive (devices need to be worn), and time-consuming techniques. Overall, the results showed that changes in certain features of PD, such as tremor, coincided with changes in the UPDRS. Testing showed that any changes in tremor and motor function found by the device, was a statistically significant ($p = 0.047$) predictor of change in the UPDRS rating. Therefore, suggesting that the tool has the potential to be used as a home-based form of monitoring.

A similar at home PD monitoring device has been proposed that uses a combination of self-assessments and motor tests [11]. The device itself is a handheld computer with a touch screen interface. It provides the user with a series of self-assessment questions such as "how is your condition right now?" which needed to be answered several times daily [11]. Users were also asked to carry out both cued and uncued finger-tapping tests using the touch screen. The final test carried out by the device was a spiral drawing test. Each of the motor tests collected data on upper limb stiffness, slowness of movement and involuntary movement. Once the data were collected, they were sent in XML format to a central repository for later analysis. Sixty-five people with PD took part in an evaluation of the device. Correlation analysis of the finger-tapping and spiral tests provided different and more in-depth information than the basic self-assessment questions [11]. Participants were asked to use the system before and after treatment to establish if it could identify a difference. For many of the participants, a significant difference was found between the tests carried out before and after treatment. Compliance was high among the participants suggesting that they were happy using such a system.

The proposed home-based monitoring and assessment tool to be presented within this paper aims to draw on similar methods as those discussed above. The novel approach that we have taken emphasizes the need to ensure that participants do not need to wear any body worn device, in order to be monitored. Similar to the two studies discussed, this tool monitors features of PD such as, bradyknesia, akinesia, rigidity, and tremor with a view to identifying their clinical status. As with the studies discussed above, the proposed home-based monitoring tool to be presented endeavors to make the process of monitoring PD more objective.

IV. METHODS

A. Tool

A computer-based PD monitoring and assessment tool used within this study has been created to collect information on hand and finger movements. The assessment tool was developed using Visual basic.NET 2008 and can deployed on any computer running the.net framework [14]. For the purposes of this study, we focused on the use of the tool on a standard computer running Microsoft Windows. Each of the participants was given laptops with identical hardware and software configurations in order to maintain consistency. The tool was designed to engage the user to make a series of mouse movements and clicks in order to collect data on various elements of their movement. The data collected by the tool were speed of movement (pixels per s/ms), location of clicks (x, y coordinates), time stamps showing the time taken to use the tool (s/ms), distance covered (pixels), and a visual representation of the path taken (scalable vector graphics). Fig. 1 provides a diagram showing the outputs from the tool.

Each of the data packets collected acted as a proxy for certain features of PD (see Table II).

B. Evaluation and Participants

The aim of the research was to establish if the data collected by the monitoring tool could effectively identify "on" and "off" states on a daily basis without the requirement for regular clinical assessment. Ten people diagnosed as having PD, according to Brain Bank criteria, were recruited from the

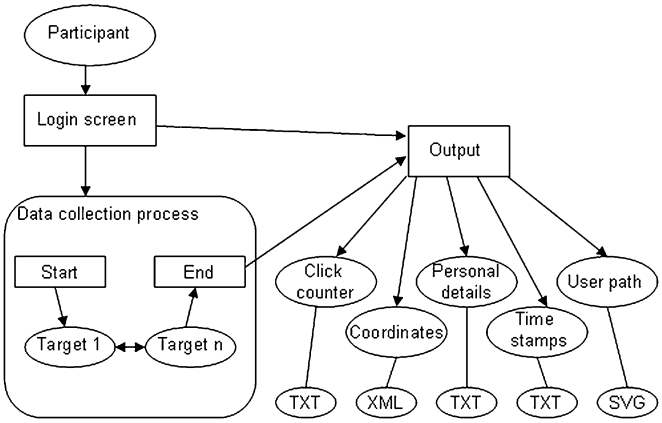


Fig. 1. Diagram showing the processes and outputs from the monitoring tool.

TABLE II
SHOWING THE FEATURES OF PD AND THE DATA COLLECTED BY THE TOOL, WHICH COULD HELP IDENTIFY EACH FEATURE

Feature	Data Collected to Identify Feature
Tremor	Distance expressed as a % difference from straight line movement; number of direction changes; count of accidental clicks.
Akinesia/Freezing	Count of the number of stops; length of each stop.
Bradykinesia	Movement time taken to click each target; time taken to click each target when within the target area; time taken to leave the target area; average speed of movement.
Rigidity	Time taken to click a target after mouse over; overall time taken; average speed of movement.

Regional Movement Disorder Clinic, Belfast City Hospital and a number of PD Society branches. The participants were predominately male aged between 63 and 77 years of age and characterized using the UPDRS and Hoehn and Yahr rating scales (see Table III) [15], [16]. For the remainder of this paper the participants will be referred to as PD participant n (PDPn).

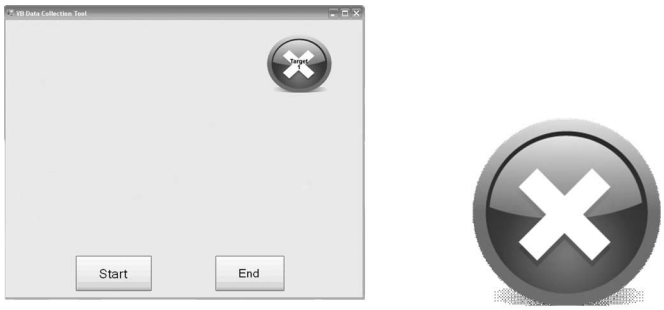
Before taking part, each participant was provided with an information sheet outlining the study and asked to sign a consent form, in accordance with the Office for Research Ethics Committees Northern Ireland (ORECNI) ethical approval. The clinical assessment of each of the participants was carried out by a PD nurse. Medication compliance can often be a factor for people required to take it daily; however, throughout this evaluation, there were no medication compliance issues. This was verified both by the data collected and by the carer of the participant. One participant ran out of medication during the evaluation period however, they got more as soon as possible.

C. Using the Tool

A notebook computer with the monitoring tool installed was provided for each participant to use over a four-day period in their own home. Although laptops were provided for the purposes of the evaluation, it is hoped that in the long term the tool could simply be installed on a person's home computer. This would mean less inconvenience for the user as they would not need extra equipment around their home. For those who do not own a computer, this form of assessment may not be suitable for them. Participants were asked to use the tool twice a day, once when they were in their "on" state and once in their "off" state, for the four days and to record their participation. In order to verify that the person was in fact "on" or "off" at the time of using the tool, the information on the time since the last dosage of medication was referred to. Prior to taking part in the

TABLE III
PARTICIPANT DETAILS: AGE, GENDER, UPDRS RATING, HOEHN & YAHR RATING, CLINICAL INFORMATION (COLLECTED BY A PD NURSE) AND MEDICATIONS TAKEN FOR EACH PARTICIPANT

PDP	Age	Gender	UPDRS Rating	Hoehn & Yahr
PDP1	75	Female	57/199 *(i. 2, ii. 16, iii.39, iv. 1)*	4-5
	Clinical Info		Diagnosed with PD in 1991, (18 yrs ago). Mobility has deteriorated over the years and tremor has developed. Difficulty grasping and with fine motor movements.	
	Medication		Pramipexole, Selegiline, Amantidine	
PDP2	68	Male	96/199 *(i. 6, ii. 31, iii. 56, iv. 3)*	4
	Clinical Info		Diagnosed with PD in 1996 (12 yrs ago). Mobility not good, posture stooped, shuffly short steps at times. Noticeable tremor present in both hands.	
	Medication		Co-beneldopa	
PDP3	66	Male	29/199 *(i. 1, ii. 10, iii. 17, iv. 1)*	2-2.5
	Clinical Info		Diagnosed with PD in 2001 (8 yrs ago). Has a right sided pin rolling tremor, which is now controlled better that he is on levodopa.	
	Medication		Ropinirole, Co-beneldopa	
PDP4	77	Male	34/199 *(i.4, ii.12, iii.17, iv.1)*	2
	Clinical Info		Diagnosed with PD in 1999 (10 yrs). Has a slight tremor in his right hand which is worse when cold. His posture is stooped and he shuffles.	
	Medication		Ropinirole, Co-beneldopa	
PDP5	65	Male	77/199 *(i. 4, ii. 22, iii. 47, iv. 4)*	3-4
	Clinical Info		Diagnosed with PD in 1999, (10 yrs ago). Mobility now limited in distance, slow and shuffly, short steppage, sometimes has festinating gait. Balance poor. Tremor quite pronounced but stops with action if moves hands.	
	Medication		Co-careldopa plus COMT inhibitor, Co-beneldopa, Rasagiline	
PDP6	64	Male	57/199 *(i. 2, ii. 16, iii. 34, iv. 5)*	3
	Clinical Info		Diagnosed with PD in 2004 (5yrs). Tremor on action mainly. Evidence of rigidity, severe on left side. Movements in hands moderately impaired.	
	Medication		Pramipexole	
PDP7	64	Male	46/199 *(i.3, ii.12, iii.30, iv.1)*	3
	Clinical Info		Diagnosed with PD in 1990 (19yrs). No tremor at present. Generally feels slow and stiff. Mild/moderate rigidity evident all over.	
	Medication		Co-careldopa, Pramipexole, Amantidine	
PDP8	74	Male	80/199 *(i. 4, ii. 21, iii. 52, iv. 3)*	3
	Clinical Info		Diagnosed with PD in 2004 (5 yrs ago). Mobility currently limited in distance, mobile about house. Right side does not move at all, so compensates with left. Tremor in right side only, present most of the time and marked.	
	Medication		Co-beneldopa	
PDP9	63	Male	43/199 *(i. 2, ii.13, iii. 24, iv. 4)*	3
	Clinical Info		Diagnosed with PD in 2003 (6 yrs ago). Mobility gradually getting worse, freezing and poor balance at times. Mobility limited in distance.	
	Medication		Co-careldopa	
PDP10	66	Male	20/199 *(i.1, ii.4, iii.15, iv.0)*	2
	Clinical Info		Diagnosed with PD in 2005 (4 yrs). Slight tremor present in left hand though most of the time it is not present, worse if he gets tired. Mobility limited in distance, tires easily, generally slower at all activities than previous.	
	Medication		Ropinirole, Co-careldopa.	



(a) (b)

Fig. 2. (a) Screenshot of the main. (b) Target used in the tool screen after the start button has been pressed.

evaluation each participant was given several demonstrations of the tool in use and then tried it themselves a couple of times.

The monitoring tool initially presents the participants with a personal details screen where they added details such as, name, gender, medication and time since last dosage of medication.

Once the user has entered the main application (see Fig. 2(a)) monitoring began once the participants clicked on the "start" button. Clicking on this button subsequently made a target appear on the main screen (see Fig. 2(b)). Participants were then asked to move the mouse towards each target as it appeared on screen and click on it. As each target was clicked, it would disappear and a new one would appear in a random location. This process was repeated for ten targets.

Once all ten targets had been clicked the participant then clicked the "End" button and the tool closed. All of the movement data were then saved for analysis. In order to identify the statistical significance of the difference between "on" and "off" state for each person, the Wilcoxon rank sum test was used [17]. Although this significance test is predominantly used on two independent samples that used the same test, the participants "on" and "off" results, in this evaluation, are essentially two independent samples as their condition and abilities are very different in each instance. The test itself remains the same however, the state of the participants are considerably different. Each of the features, presented in Table II, can present themselves differently depending on whether the person is in an "on" or "off" state, therefore providing a different case in each state.

V. Results

A. Time Analysis

The main observation in the analysis of the time taken to complete the assessment was that participants were able to do so more quickly when in the "on" state. The analysis was carried out using the MATLAB software. Although this was the case for all ten participants, there was variability in the extent to which this was the case. The percentage differences between each participant's "on" and "off" state are presented in Table IV.

Table IV highlights that each participant can show varying time when considering results on a daily basis. PDP1 goes from only a 0.67% extra time taken when "off" compared to "on" and then on day four the increase rises to 25.42%. PDP5 shows

TABLE IV
Shows the Percentage of Extra Time Taken to Use the Tool When "Off" Compared to "On" for Each Participant Over the Four Days

PDP	% Time Difference Day 1	% Time Difference Day 2	% Time Difference Day 3	% Time Difference Day 4
PDP1	0.67	1.06	29.37	25.42
PDP2	66.79	31.49	26.34	34.55
PDP3	9.19	31.14	5.68	2.96
PDP4	45.70	43.31	42.51	13.84
PDP5	9.77	17.98	3.37	14.78
PDP6	40.50	2.93	8.68	16.51
PDP7	14.93	29.09	11.10	44.74
PDP8	28.22	52.56	66.21	72.41
PDP9	5.51	12.89	37.93	26.92
PDP10	13.23	6.88	29.95	5.30

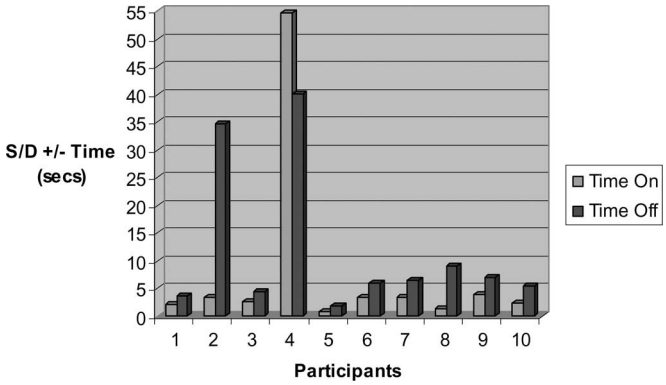


Fig. 3. Standard deviation in time taken (in seconds) to use the tool when "on" and "off" for each participant over the four days.

relatively consistent results over the four-day period with regards to difference between "on" and "off" except for day 3. To further highlight the level of variance in time taken on a daily basis for each participant, Fig. 3 shows the standard deviation when "on" and "off" over the four days for each participant.

Fig. 3 highlights that all of the participants, except for PDP4, showed more variance in time taken to use the tool when "off" compared to "on". PDP4 was an exception to the trend that the "off" states showed more variance in time taken than the "on" states. This could be explained by this participant running out of their medication during the evaluation period, and therefore, did not have an accurate "on" state for two of the four days. The data collected by the tool was able to distinguish a statistically significant difference ($p = 0.017$) in the "off" and "on" states for all of the participants combined. In order to establish if there was any correlation between duration of the disease, clinical ratings and time taken, Table V presents all of this data together.

Table V shows that the PDP2 has the highest UPDRS rating and a high H and Y rating and their daily differences in "on" states are considerably less than the daily differences of the "off" states. The same can be seen with the standard deviation when "on" and "off" for this participant, the "off" state shows considerably more variance than the "on" state. The participant with the second highest UPDRS rating, PDP8, showed a visible difference in the "on" states from day to day compared to the

TABLE V
SHOWS THE LENGTH OF TIME EACH PARTICIPANT HAS HAD PD, THE UPDRS RATING, HOEHN & YAHR RATING; DIFFERENCE (IN SECONDS) OF TIME TAKEN FROM DAY TO DAY, AND THE STANDARD DEVIATION (SECONDS) WHEN "ON" AND "OFF" FOR EACH PARTICIPANT

PDP	PDP1	PDP2	PDP3	PDP4	PDP5	PDP6	PDP7	PDP8	PDP9	PDP10
Duration of Disease	18 yrs	12 yrs	8 yrs	10 yrs	10 yrs	5 yrs	19 yrs	5 yrs	6 yrs	4 yrs
UPDRS	57 /199	96 /199	29 /199	34 /199	77 /199	57 /199	46 /199	80 /199	43 /199	20 /199
H&Y	4-5	4	2-2.5	2	3-4	3	3	3	3	2
Diff 'On' Day 1-2	0.252	0.922	5.091	26.468	1.610	7.751	8.078	1.594	0.000	5.564
Diff 'On' Day 2-3	1.750	6.829	0.533	25.422	1.002	3.580	4.234	0.877	5.891	2.829
Diff 'On' Day 3-4	2.436	6.093	1.296	98.498	1.363	2.453	0.020	0.686	1.204	1.874
Diff 'Off' Day 1-2	0.157	64.091	1.501	54.704	1.578	10.891	5.875	6.781	4.156	4.001
Diff 'Off' Day 2-3	7.579	13.299	8.501	42.330	4.547	1.533	0.360	8.125	11.971	6.812
Diff 'Off' Day 3-4	4.998	14.874	0.750	55.034	2.736	0.470	13.499	5.316	11.471	12.328
S/D On	2.05	3.51	2.56	54.70	0.91	3.36	3.30	1.36	3.78	2.46
S/D Off	3.54	34.65	4.31	40.07	1.89	5.91	6.47	8.91	6.92	5.51

TABLE VI
SHOWS THE PERCENTAGE SLOWER THE PARTICIPANT'S MOVEMENTS WERE WHEN "OFF" COMPARED TO "ON" OVER THE FOUR-DAY PERIOD

PDP	% Speed Difference Day 1	% Speed Difference Day 2	% Speed Difference Day 3	% Speed Difference Day 4
PDP1	19.16	29.89	16.62	28.35
PDP2	29.87	27.25	32.44	49.11
PDP3	30.85	13.88	8.22	2.96
PDP4	6.41	39.08	2.20	59.93
PDP5	21.75	24.30	3.21	15.64
PDP6	19.02	6.75	20.60	12.01
PDP7	38.57	31.59	25.07	12.80
PDP8	24.43	52.23	49.99	70.89
PDP9	20.15	17.95	19.55	16.04
PDP10	52.61	11.28	38.41	59.18

daily "off" states. Similarly, there is quite a difference in the standard deviation when "on" compared to "off" for this participant. As the clinical ratings reduce, the difference in the daily time taken when "on" and "off" starts to decrease. The clinical ratings seem to have more impact on the time taken results than duration of the disease. As previously discussed, PDP4 ran out of medication during the evaluation period and as a result their deviation was more when in the "on" state rather than the "off" state in contrast to all of the other participants. PDP5 showed the least amount of difference between deviation when "on" and "off". Interestingly this participant was due to change to a different medication the week following the evaluation period.

B. Speed Analysis

Table VI presents the percentage slower participants moved when "off" as opposed to "on". All of the participants used the tool at a slower speed (pixels covered per second) when they were in an "off" state again with a high degree of variability.

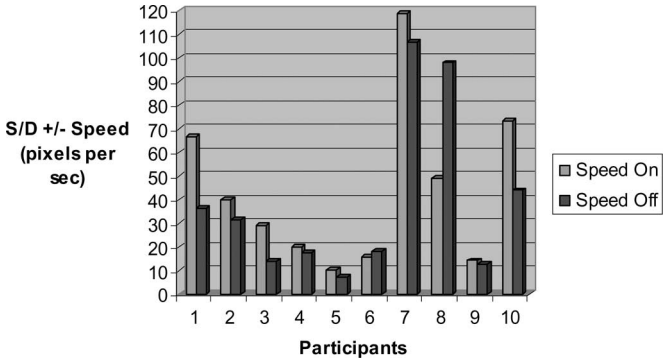


Fig. 4. Standard deviation in speed of movement (pixels per second) when "on" and "off" for each participant over the four days.

Similar to the time taken results, previously discussed, the speed of movement results, are quite varied. This level of variance in speed of movement on a daily basis for each participant, is further highlighted in Fig. 4, which shows the standard deviation when "on" and "off" over the four days for each participant.

Fig. 4 highlights that all of the participants, except for PDP6 and PDP8, show more variance in speed on a daily basis when in the "on" state. The difference in variance with PDP6 is quite minimal, however, the difference seen in PDP8's results is marked. This participant also has one of the highest UPDRS ratings and showed a marked difference in standard deviation when "on" compared to "off". In order to establish if there is any correlation between duration of the disease, clinical ratings and speed of movement results, Table VII presents all of this data together.

The data collected by the monitoring tool (presented in Table VII) helped identify that the majority of participants show more variance in speed of movement on a day to day basis when in the "on" state. Although PDP6 and PDP8 both show that the variance in speed of movement is greater when "off" compared to "on," PDP8 shows the most marked difference. This participant has a high UPDRS rating and is said to have marked tremor, which is worse when off. The greater variance in speed, when "off," for PDP8, could be explained by the clinical information collected.

VI. DISCUSSION

The data collected from the evaluation of the home-based monitoring and assessment tool demonstrated that a difference can be identified between the "on" and "off" state. Analysis of time and speed of movements highlight a difference when each of the participants was "on" as opposed to "off." Some participants showed a larger difference in the results collected when "on" and "off," whereas others presented a minimal difference. This was an anticipated outcome as each person with PD can experience different features and also different levels of the disease. Also, each person reacts differently to each medication prescribed to them. This is why close monitoring of the effectiveness of the current medication that people are taking is needed. This tool looks at all aspects of each person's level of PD combined with data on time taken and speed of movement

TABLE VII
LENGTH OF TIME EACH PARTICIPANT HAS HAD PD, THE UPDRS RATING, HOEHN & YAHR RATING, DIFFERENCE (PIXELS PER SECOND) OF SPEED OF MOVEMENT FROM DAY TO DAY AND THE STANDARD DEVIATION (PIXELS PER SECOND) WHEN "ON" AND "OFF" FOR EACH PARTICIPANT

PPD	PDP1	PDP2	PDP3	PDP4	PDP 5	PDP 6	PDP 7	PDP 8	PDP9	PDP10
Duration of Disease	18 yrs	12 yrs	8 yrs	10 yrs	10 yrs	5 yrs	19 yrs	5 yrs	6 yrs	4 yrs
UPDRS	57 /199	96 /199	29 /199	34 /199	77 /199	57 /199	46 /199	80 /199	43 /199	20 /199
H&Y	4-5	4	2-2.5	2	3-4	3	3	3	3	2
Diff (pixels per sec) 'On' Day 1-2	124.52	9.44	59.20	6.74	1.59	6.62	120.65	57.96	18.72	42.07
Diff (pixels per sec) 'On' Day 2-3	151.27	76.63	1.26	23.69	20.43	10.68	169.19	40.71	34.47	46.50
Diff (pixels per sec) 'On' Day 3-4	38.02	75.91	0.00	48.24	22.16	18.97	166.80	8.32	16.87	172.24
Diff (pixels per sec) 'Off' Day 1-2	60.93	10.24	1.34	33.16	2.60	24.43	99.96	148.77	18.45	85.77
Diff (pixels per sec) 'Off' Day 2-3	76.99	44.58	15.28	7.14	11.92	13.04	150.92	11.93	30.28	98.03
Diff (pixels per sec) 'Off' Day 3-4	1.54	74.50	13.16	14.44	2.56	30.95	79.30	72.82	18.56	26.87
S/D On	66.77	40.04	29.19	19.96	10.33	15.84	119.08	48.88	14.09	73.18
S/D Off	36.29	31.53	14.08	17.62	7.03	18.18	106.68	97.95	12.66	43.89

in order to establish a "normal" pattern for each individual. It is hoped that long term use of the tool would enable this "normal" pattern to be identified for each person and for a clinician to be alerted if there was any deviation from this pattern.

The difference in time taken results for each of the ten participants, presented in Fig. 3, highlights just how different each person's times over the four-day period were. Background clinical information combined with the statistics on time taken can help to gain a deeper understanding of the clinical status of the participant and the degree to which their PD is impacting upon them. The main result, which stands out from Fig. 3, is from PDP4 as it shows more variance in the "on" state. As previously discussed, the standard deviation in time taken for PDP4 is very high on both "on" and "off" states. For the majority of the participants, although there is a difference in the results produced when "on" as opposed to "off," the time taken is quite similar on each of the days. Nevertheless, PDP4 did not show this consistency due to a lack of the appropriate medication during the evaluation period. Essentially, the results produced by a participant who was not on the required medication can be clearly identified among all ten participants' results. This, in many ways, indicates that the data collected by this home-based monitoring tool has the potential to identify any problems with medication.

Similarly, the difference in speed of movement results, which are presented in Fig. 4, show a wide range of levels of variance between the "on" and "off" state. One set of results that particularly stands out are those from PDP8. This participant's speed results are quite erratic and change quite considerably on a day to day basis as well as when "on" and "off." The clinical assessment carried out on PDP8 revealed that this participant experiences stiffness at various times of the day. The clinical information sheets completed during the evaluation by the participant showed that they completed the tool at a different time of day on each of the four days. This could explain the inconsistent speed results over the four days. This suggests that although this four day evaluation can begin to identify the potential of this monitoring tool to identify a "normal" pattern for "on" and "off" state for each participant, a longer evaluation is needed to confirm patterns.

Overall, the outcomes from this evaluation are promising as they suggest that, even at this initial stage of evaluation, we can identify the difference in the "on" and "off" state for each participant. A limitation of the study is that it can be difficult for a person with PD to clearly identify their "on" and "off" state. However, when the information on the time since the last dosage of medication is combined with the person's opinion on their "on" and "off" state it can be further confirmed. Once this "normal" pattern for each person has been established, any extreme changes in the pattern can then be flagged and brought to the attention of the clinician. The results from PDP4 and PDP5 have noticeable differences to those of the other eight participants. As PDP4 ran out of medication during the evaluation period and PDP5 was due to change medication the week after the evaluation, it is promising that the monitoring tool identified these abnormalities. The analysis of the data collected from this evaluation was carried out manually, however future work includes automating this process. Ideally, a larger number of participants and monitoring over a longer period of time would have been preferred. Nevertheless, this evaluation provided valuable indicators as to the potential of this tool.

VII. FURTHER WORK

Ideally, future work would include a further evaluation period that runs over a longer period of time (around 6 months) and with a larger group of participants. With the data collected over this longer period, trend analysis could be carried out to determine any true trends in the data. This would allow for further justification of the use of the home-based monitoring tool. At present, all data collected was analyzed manually. An instant classification system is essential to allow for decisions to be made by the system at certain points on whether the user's "on" and "off" states are still "normal" for them. If not, the clinician would be informed. In order to further explore the tool's potential to identify any problems with the current medication a person is on, an evaluation involving a number of people with PD in need of a change in medication would be required.

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