A Game Approach for Monitoring of Parkinson Disease Motor Symptoms

ABSTRACT

Parkinson's disease (PD) is a degenerative neurological disorder, which affects the patient's movement by causing motor symptoms such as tremors or bradykinesia. The disease's progressive nature requires regular monitoring of these symptoms to inform a careful adaptation of the dosage of medication, especially considering various side-effects of the currently available pharmaceuticals. Here we propose a game environment capable of tracking motor signs non-intrusively at the user's home. Embedded in the daily routine, the monitoring thus becomes more frequent and cost-effective, leading to a better management of the treatment and consequently increases the patients quality of life. The evaluation of this approach was applied with 27 research subjects, divided between control group and PD group, and the results showed it is possible to identify and quantify the occurrence of bradykinesia symptoms.

Categories and Subject Descriptors

J.3 [**Life And Medical Sciences**]: Health information systems

Keywords

Parkinson Disease, Game for Health, Game Development, Continuous Health Monitoring

1. INTRODUCTION

About 2% of the world population over the age of 65 years suffers from a degenerative neurological disorder known as Parkinson's disease (PD). This disease affects the patient's movement by causing motor symptoms such as resting tremor, bradykinesia (i.e., slowness of movement), and gait disorders marked by rigidity and postural instability. Although these symptoms can be reduced by appropriate medication, the progressive nature of PD, which worsens in sudden fits rather than a predictable continuous fashion, requires a frequent monitoring of the symptoms. The better the information about the symptoms' development, the more accurate a neurologist or physician can prescribe the required medication dosages. Considering the various side-effects of the currently available pharmaceuticals, a precise level of medication can have a significant impact on the patient's quality of life.

Given the importance of the monitoring of motor symptoms, many approaches and technologies have been developed in order to track motor symptoms related to PD and similar disorders [4, 10, 11]. Developers usually aim at moving healthcare services from the hospital to the home to make them more cost-effective, frequent and convenient for the user. Many of the proposed approaches therefore rely on so-called "wearables", sensors attached either directly on the user or in her clothing (or shoes) that allow for remotely measuring tremor, gait patterns [11], or posture by a video recording system [4]. These sensors then communicate with hardware in the user's home (which may forward processed data to the physician) to create a pervasive environment that "keeps an eye" on the user's health status [10]. A major challenge for such wearable technologies is the acceptance by the user, who may consider these devices disturbing, stigmatizing, or overly interfering with user's privacy [1]. We then developed a gme prototype using a commercial consumer eletronic motion sensor as an input device and tested it with research subjects to evaluate the proposal. In order to develop an unobtrusive technology that integrates smoothly into the user's daily routine and does not create a negative perception towards the devices that surround the user, then from user's perspective it is more comfortable to use a seamless health monitoring technology with out reminding the patient of the treatment [1]. Since mid 2006, the game industry has developed motion sensors that capture physical activity in order to evaluate the user's health condition and encourage the user to pursue a healthier lifestyle [12]. Some systems can also be used to monitor vital signs such as heart rate [3]. Some mobile applications are employed to motivate the physical activity more directly, such as the prototypes of "Trance", "Feeding Yoshi" and "Nokia Wellness Diary and Sports Tracker", which promote healthy activities and regular exercise in an immersive, entertaining and engaging manner [13].

In this work, we propose a game approach that was developed with these two important aspects in mind. The contact-less measurement of the user's motor symptoms is embedded in the motivating context of a game, emphasizing the users abilities rather than their health limitations. The use of common consumer electronics for electronic games

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(which might be already present in some users' homes) allows for a cost-effective employment of the system without interfering with the user's privateness. Then we developed a game prototype using a commercial consumer electronic motion sensor as a input device and tested with research subjects to evaluate the proposal.

2. BACKGROUND

2.1 Parkinson's Medication Management

The symptoms associated with PD are known to be caused by a degeneration of dopaminergic neurons in the substantia nigra, which leads to a decreased stimulation of the motor cortex. Common treatments are therefore focusing on the neurotransmitter dopamine, either by drugs that activate dopamine receptors or by medication with levodopa, a biosynthetic precursor of dopamine that can cross the blood-brain barrier into the brain where it is metabolized into dopamine. Since PD is a chronic disease that progresses over the years, the medication decreases in effectiveness and higher dosages are required [7]. The complex combination of unsteadily increasing motor and non-motor symptoms (such as cognitive dysfunction and language problems), together with the side-effects of the medication, make it difficult to determine the right medication dosage and requires it to be regularly readjusted.

The situation is additionally complicated for patients in a later stage of the disease. After an initial period, which can last for several years, in which the medication with levodopa suppresses the symptoms relatively successfully, patients experience the so-called "on/off" phenomenon. This phenomena describes sometimes unpredictable fluctuations of symptoms during medication intervals. In the "off state", rigidity and bradykinesia acutely worsen for minutes or even hours [7]. While for some patients this effect is somewhat predictable, for others the phenomenon does not correlate with the medication interval. This condition makes it hard for a physician to determine the right level of medication with only the information at hand that can be gained in the few minutes of a consultation.

One of the main objectives of the game model approach discussed below is to therefore provide the physician with data from frequent measurements of the patients motor symptoms. This data can help the physician to make better informed decisions about the prescribed medication dosages and intervals, and thus to reduce side-effects and ultimately improve the patients quality of life.

As a possible usage scenario for this research, we can assume a user who is suffering a chronic and progressive disease such as PD, which causes motor symptoms and requires them to take medication that suppresses these symptoms. By playing a specifically designed game, such as the one described below, they can have their motor symptoms detected and recorded at their home at different times of the day. As time goes by, the patient takes the data gained while playing to a consultation with their physician. With the aid of the processed data, the physician makes an assesment, of the progress of the disease and prescribes an appropriate level of medication.

2.2 Related Work

The idea of exergames has been using encouraging physical activities to detect and assess the movements of players with motor deficiencies. Atkinson and coworkers [2] developed a game environment around a touch sensor that records the players movements as they try to reach specific targets. The data gained by the "Novint Falcon Human Interface Device", as it is named by the authors, is meant to facilitate a better medical diagnosis of PD. However to the best of our knowledge, no system trial has yet been reported. Another interesting approach has been suggested and tested by Synnot *et al.* [14], who use a common game console already employed for exergames to capture PD motor symptoms, in particular tremor. The player has to perform a series of motor tasks presented in the form of mini-games, while holding a Nintendo Wii Remote Control (NWRC). A metric analyzer provides objective metrics detailing the user performance and records them in an electronic patient diary. The diary also includes the patient's self-reported medication intake and symptom self-rating. However, one major disadvantage of the group's focus on tremor is the dependence of tremor on the user's attention state. We observed in our own research how the tremor can be suppressed (usually unintentionally by the user) while the user is concentrating on the game, in particular if the player's hand is involved.

The approach presented in this work is also based on a common, relatively low-cost game console, yet with the main difference is that the motion sensor works contact-free and does not require the player to hold or wear any object. This apparently minor detail can make a difference in the players movements, especially if they are affected by motor symptoms, as pointed out by several neurologists when asked for advice for the designing of this approach. Furthermore, we measure the same type of movement that is commonly used by neurologists to assess PD related motor symptoms, viz. the arms' abduction and adduction, which are significantly more stable than tremor. The engaging and entertaining context of the game can thus distract the player from the health monitoring without interfering with the observed feature, which further improves the quality of the data gained during the measurement.

3. THE PROPOSED APPROACH

The proposed system interacts on the input side with the user, which in our user scenario would be a person suffering motor symptoms, and delivers output to a healthcare professional, helping them to assess the symptom in order to achieve a better informed medication management. The system itself (as depicted in Figure 1) consists of 4 main components, the data acquisition by a video based full body motion sensor, a health game monitor as an acquisition system, the signal processing, which is subdivided in biomechanical and signal processing patterns identifications techniques, and finally the data visualization for the physician. To provide a measure for the severity of the motor symptoms, the classifier in the signal processing step is trained to distinguish between the moving pattern of healthy subjects and those of subjects diagnosed by neurologists as suffering from PD. This classifier output, along with a summary of the processed biomechanical data, is then graphically displayed to inform the healthcare professional.

In the development of the system outlined above, we had to consider various facets and concerns such as: the elderly users' health and acceptance, technical limitations and cost, and game and motivation related aspects. More specifically, the goal was to design a system that also elderly users with

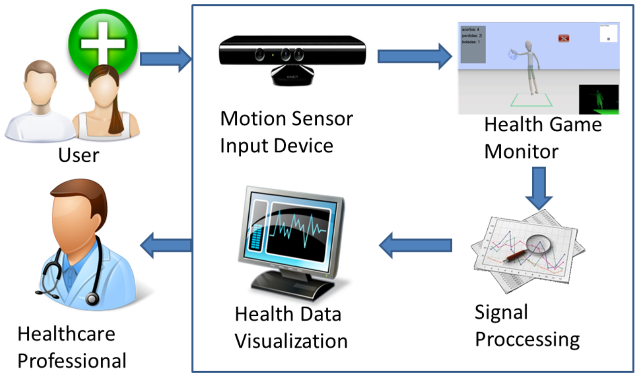


Figure 1: System Overview

motor disorders are willing to employ at their home according the following requirements:

1. The equipment has to be easy and safe to use. Besides a simple setup of the hardware, the user interface should be simple and clear with large font and buttons.
2. Of particular concern are the physical and cognitive limitations of the players [8], including the possibility of the acute off-state of a PD patient. The system should never prompt the player to make movements that could cause them to fall or suffer physical harm.
3. The game has to nonetheless incite the player to perform specific movements that are required for the measurement, in particular arm abduction and adduction on both sides. The recoded movements should allow the system to detect the maximal height and angle of the adduction as well as the speed of the movement;
4. The measurement should be contact-less, without requiring the user to wear or hold any object.
5. Since elderly players tire quickly, which affects the player's motivation and distorts the measurement, the measurement has to be performed in a reasonably short time;
6. To motivate the player and distract them from the measurement, the game needs to articulate a clear and entertaining goal, adapt the level of difficulty to user skills and show the users her progress, e.g. via a score [12, 13];
7. Processed data should be presented in a clear and informative visual way to the physician reviewing the data;
8. To reduce both development time and material cost, especially later on for the user, common consumer electronics such a game console should be used.

3.1 System Architecture

Figure 2 illustrates the system architecture in more detail. The **input** is received from the players movements via a video based full body motion sensor 'Kinect' Version 1.0[1], which was developed by Microsoft Game Studios. The device projects a light grid in near infrared onto the player and records it with a video camera to identify and track the 3D coordinates of the players body parts joints and anatomical position [9].

[1]www.microsoft.com/en-us/kinectforwindows/

The software libraries from Zigfu[2] and Unity 3D[3] were used to capture the players position and movements in 3D coordinates and render the game. The acquisition signal is imported into the Matlab to calculate these coordinates into biomechanical signals and make it possible to determine severity or degree of the motor symptoms with a generalized linear model. Those technologies are under active development, and therefore allow the Health Monitor Game (HMG) system to be easily adapted to (and benefit from) future changes in both hardware and third party software. Unity's cross-platform ability in principle also offers a portability of the system to other suitable environments.

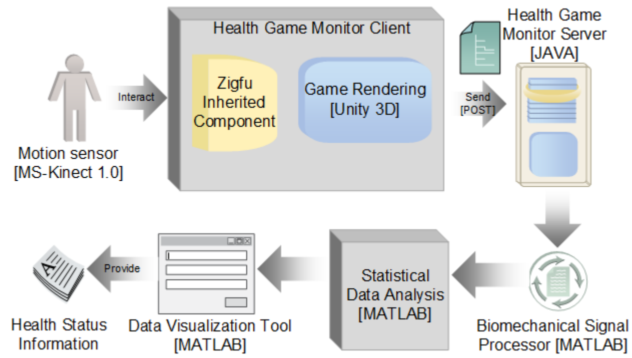


Figure 2: System Architecture

Together, the Zigfu and the Unity 3D processes build the core of the HMG client, which communicates with the HMG server via POST[4]. At the end of each session, the user data, including the 3D coordinates of the players body recoded during the game, is uploaded to the server in JSON[5] format and saved in the server's PostgreSQL[6] database. From there, the data is accessed by the signal processing component to calculate the players motor abilities and extract features to estimate the severity of the motor symptoms. Finally, the results are reported to the health care professional in a combination of visual and tabular form, featuring direct biomechanical measures that specialist are familiar with from PD diagnosis handbooks [7], as well as the mechanisms to estimate of the patients level of motor deficiency [7]. The latter is a single number between 0 and 1, making it easier for the specialist and the user to track changes in the user's symptoms each time the game was played.

3.1.1 *Implementation*

To verify the approach described in this work, a prototype system of a HMG was developed according the proposed System Architecture (Figure 2) to verify the feasibility of development. We developed a prototype named as *"Catch the Spheres"* (Figure 3) according the requirements listed above.

The player controls an avatar with their movements, who has to catch balls that approach from the horizon at varying heights and with different speeds. Controlling the height and speed of the balls, it is possible to incite the player to

[2]www.zigfu.com
[3]www.unity3d.com
[4]www.w3.org/
[5]www.json.org
[6]www.postgresql.org

execute specific movements and thus test the player's motor abilities.

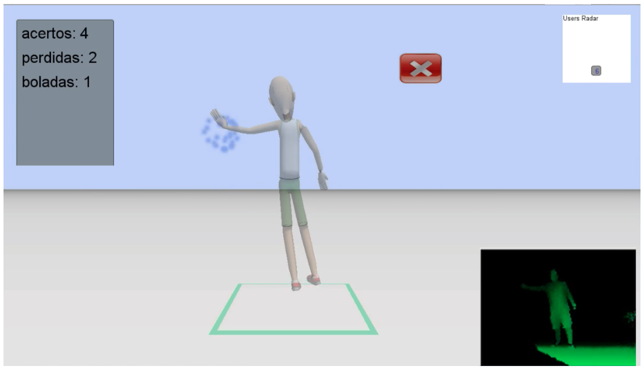


Figure 3: Screenshot of sample game *Catch the Spheres*. The player has just successfully caught a sphere that flew at him from the horizon.

3.1.2 *Biomechanical Signal Processing*

The biomechanical signal processing 4(b) was greatly influenced by semi-structured interviews [6] with two neurologists and two physiotherapists who supported the research both in the design and evaluation phase. As a common part of the diagnosing and treatment process for PD, patients are asked to lift their arms, one after the other, as high as they are able to, in order to check for bradykinesia (Figure 4(a)). The maximal height reached by the patient before and after medication is noted in their medical record and assessed in combination with other symptoms to confirm or exclude PD as the origin of the symptoms. This method was adapted for the game environment not only because it performs with much more stability than observing the user's tremor, but also because arm movements are by far safer than, for example, movements of the legs that might cause the player to fall (see list of requirements above, second item).

From the 3D coordinates of the player's body parts stored in the HMG server, the position, orientation, velocity, and acceleration of the arms and hands can be calculated [9]. Since the 3D measurement is noisy, several filtering steps are applied. Some are in the Kinect system itself, and some are after the data is imported by Zigfu to the HMG client. A test series showed that Kinect data for the wrist, shoulder and hip gave the best results to construct robust features that quantify the arm's abduction and adduction. During a short game of typically 5 minutes, the player is prompted roughly 10 times to lift their right or left arm to catch a virtual ball approaching them from the horizon. The maximal height or angle, the movement's velocity, and the arm to be lifted can thus be indirectly controlled by the trajectory and speed of the ball. A random selection of the trajectories and speeds prevents the player from preparing a movement in advance.

In the first processing step for the feature extraction, the angle α between wrist and hip with the vertex in the shoulder is calculated using the scalar product. Kinect provides this data about 24 frames per second, which is handled in overlapping blocs of 1000 frames each. As shown in Figure 4(b), the resulting signal of α over time is then analyzed to detect abduction and adduction cycles. If a cycle has been detected, the signal is filtered to reduce noise, and the following features are extracted and combined in one feature vector per cycle:

- Body side (left or right arm)
- Cycle profile, normalized in time and amplitude
- Maximal angle in cycle
- Angular velocity abduction (arm lifting)
- Angular velocity adduction (arm dropping)

At times, players may not complete a cycle, such as if they give up on catching a ball deemed too fast or too high or simply because they get distracted. Such incomplete cycles are detected by comparing the cycle profile to the player's median cycle profile, and are eliminated if the discrepancy is above a threshold.

In order to provide the neurologist with a single number which makes it possible quantify the symptom over time, the data collected from 15 subjects diagnosed with PD and a control group of 12 healthy people (for details see section 4) was used to build a binomial generalized linear model [5], that would predict the probability of a player showing PD related motor symptoms based on the features extracted in the biomechanical signal processing. The model parameters were selected based on the Akaike information criterion (AIC) [5], which showed that maximal reached angles, in particular of the right arm, and the angular velocity of the adduction were better indicators than for instance the angular velocities of the abduction. The resulting model provides a value between 0 and 1 that can be used to detect symptom changes, but should not (due to the binomial regression) be interpreted as a linear measure. The combined information from this predictor and the time difference between medication intake and playing can then help the neurologist to improve the medication dosage and possibly a schedule for the patient.

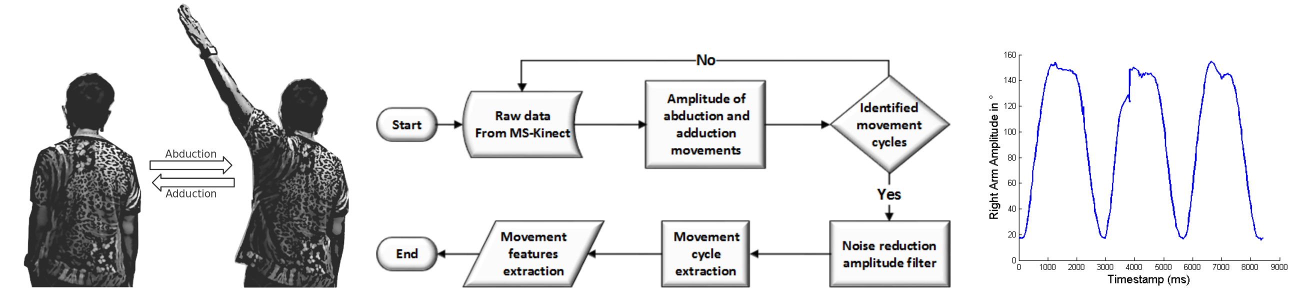
4. EVALUATION

The ethical committee of the XXXXX approved an evaluation study of the discussed approach if subjects gave their written informed consent. Each subject was instructed about the research procedure and objectives, and then asked to demonstrate upper limbs movements to ensure that there was no risk of fall for the specific subject during the study.

A total number of 27 subjects participated in the study. The group that had been previously diagnosed by neurologists with PD consisted of 15 subjects, 10 of them men and 5 women, between the age of 51 and 65 (mean: 58). The control group was composed of 12 subjects without a PD diagnosis (8 men and 4 women) with an age of 50 to 65 years (mean: 57). All subjects were interacting with the exact same system in both hardware and software, and were prompted to perform abduction and adduction of the arms according the game context. While all sessions were made in a medical institution under the supervision of a neurologist or physiotherapist to continuously check the subject's health condition, none of them needed to be interrupted to ensure the subject's safety.

4.1 Protocol

The data collection was performed from 14 June to 14 August of 2013 on different days, yet at the same location, with each subject individually. Due to time constraints and technical requirements, such as to capture with the motion sensor the entire length of the upper arm during abduction



(a) Movement of abduction and adduction (b) Biomechanical signal processor (c) Movement amplitude signal

Figure 4: Method of feature extraction

and adduction movements, each subject was instructed to perform the following steps:

1. The subject stands at distance of 2 meters from the motion sensor at a place marked for that purpose on the ground;
2. The subject faces a projection of the game on a wall, placed centric over the motion sensor;
3. The subject plays the game *Catch the Spheres* for 5 minutes;
4. The subjects ends the game by reaching for the virtual exit button (seen as red box with an 'X' in Figure 3).

5. RESULTS

Participants generally showed a very positive attitude towards the experiment, and considered the game as entertaining. None of the subjects had difficulties to interact with the system, with the exception of reaching the exit button, which some participants did not reach at the first attempt.

In order to gain a better understanding about the quality and limitations of the employed generalized regression model, we compare the value of the predictor for each subject with the neurologist's diagnosis. For each subject, the first 12 full abductions and adductions (6 for the left and right arm, respectively) cycles were extracted and transformed into feature vectors. Figure 5 shows a boxplot for the predictor values for each cycle from a subject, where the subjects 1 to 12 where not diagnosed with PD are on the left, while subjects 13 to 27, diagnosed with PD, are shown on the right. If for each subject the median predictor value (over the analyzed 12 movements) was used, the predictor could serve for classification with a robust threshold margin from about 0.58 to 0.75 and only three false negatives. Table 1 details the classification results in a confusion matrix.

Table 1: Confusion Matrix of LRM Classification

	Predictive Class	
	PD Group	**Control Group**
PD Group	12	3
Control Group	0	12

With the objective to verify a supervised learning approach, we applied the feature vectors to a Support Vector Machine (SVM) with linear kernel to classify these two groups using leave-one-out cross-validation technique [15].

Table 2: Confusion Matrix of SVM Linear Classification

	Predictive Class	
	PD Group	**Control Group**
PD Group	12	3
Control Group	1	11

Although classification in not the primary aim of this approach (considering the complexity of the symptoms and importance of a accurate diagnosis, a diagnosis should only be given by a specialized physician), this result gives a good indication about the quality of the features and the approach in general, comparing it to other results, such as posture based with a video recording system with a blue background [4] and gait analysis using foot sensors [11] see in the Table 3.

Table 3: Comparing the classification results

Metrics	*Presented Approach*		Rodrigo *et. al.* [11]	Cho *et. al.* [4]
	LRM	SVM		
TpRate	80%	80%	70,21%	95,45%
FpRate	0%	9,09%	38,87%	4,67%
Precision	100%	92,30%	73,33%	96,54%
Accuracy	88,88%	85,18%	71,11%	95,48%
F-Measure	88,88%	85,71%	71,73%	96,15%

Of special interest is the variation of the median values between subjects diagnosed with PD by neurologists. That three of them show rather low predictor values, which are comparable to healthy subjects, may indicate that they are successfully medicated and probably in a rather early phase of the disease. Furthermore, due to the nonlinear nature of the regression model, several subjects appear close to the maximal value of the predictor scale (a nonlinear transformation of the predictor scale would change the visual impression but may distort the interpretation). For some of them, the disease is already in a late phase with symptoms of severe bradykinesia. Others may require a readjustment of their medication, or the measurement took place towards the end of the medication intake interval, when the positive effects of the drugs begin to vanish.

6. CONCLUSION

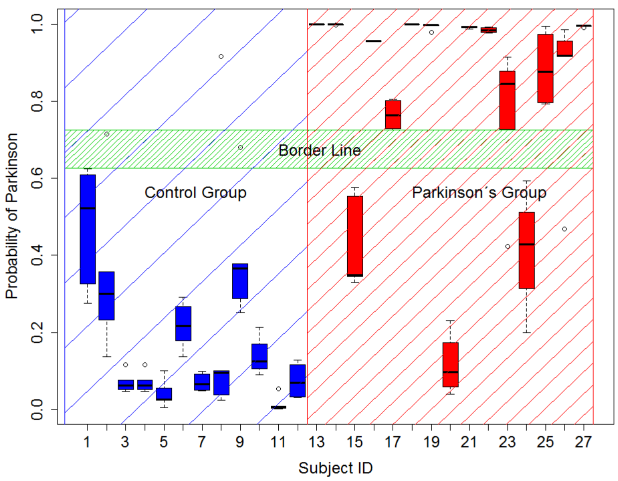


Figure 5: Boxplot of the Parkinson Disease probability. The Border Line is the frontier between the two groups.

The quality of life of patients with PD is strongly affected by medication management, which regularly has to be adapted to account for the disease's unsteady progress and to limit side-effects. Since neurologists base their decisions about the drug dosage and intake interval mainly on the motor symptoms they observe during consultation, a more frequent measurement of the patient's motor abilities can lead to a better informed medication management and thus to an improved quality of life for the patient.

The approach developed and tested in this work allows for such a frequent measurement of PD related motor symptoms in the convenience of the user's home and the entertaining context of a game. Changes in the patient's motoric abilities over time are visualized for the neurologist, among other data, with the temporal development of a single number, which summarizes the recoded motor symptom via a generalized regression model.

In contrast to related work, our approach builds on the more reliable features of arm movements (as used by neurologists) rather than tremor or gait patterns, and a contactless video-based measurement where the user is not required to hold or wear any object. By employing common consumer electronics and freely available software libraries for the game engine, the cost for the user can be small, and the development more easily adapted to improvements in both hardware and software. Furthermore, the proposed system architecture can be easily replicated and used for the development of others HMGs capable to measure player's motor abilities. More insight could also be gained by conducting a second evaluation study, measuring the progress of motor symptoms for PD subjects over several months.

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