Innovative interventions for Parkinson's disease patients using iPrognosis Games: An evaluation analysis by medical experts

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ABSTRACT

Parkinson's disease (PD) is a chronic and progressive neurodegenerative disease that affects ~7 million people worldwide, without any cure to date; however, it can be

symptomatically treated. In this vein, innovative technologies can be used for the objective assessment of clinical symptoms and to provide supportive therapies at home. The present work explores the processes and the outcomes of the i-PROGNOSIS (www.i-prognosis.eu) intervention deployment in three PD clinical centres (Greece, UK, and Germany). For that purpose, 36 PD patients were recruited to voluntarily participate in the i-PROGNOSIS feasibility study, spread across the three different countries. The PD patients interacted with the i-PROGNOSIS system for up-to-three months, mainly within the clinical environment, using the provided iPrognosis Games in dedicated gaming stations that were setup in the corresponding clinical centres. Overall, the results show that the iPrognosis Games were positively evaluated by medical experts. Moreover, based on the collected feedback, the iPrognosis Games have achieved their main goals of providing an innovative, objective and usable system for the monitoring of early PD (motor and non-motor) symptomatology, by providing tools for complementing existing clinical interventions for the improvement of PD patients' quality of life.

CCS CONCEPTS

• Human-centered computing • PD management • Serious Games • PD interventions • PD monitoring tools • Healthy and Active Ageing

KEYWORDS

Parkinson's disease (PD), i-PROGNOSIS, iPrognosis Games, i-PROGNOSIS Motor Assessment Tool (iMAT), Medical Experts' Evaluation

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1 INTRODUCTION

Parkinson's disease (PD) is progressive and one of the most common neurodegenerative disorder, affecting approximately 1% of individuals over the age of 60, causing progressive disability that results in a burden of ~2.2 million disability-adjusted life years (DALYs), exhibiting the greatest loss of quality-adjusted life years (QALYs) among 29 major chronic conditions [1], [2]. In the area of neurological disease, research is being conducted into novel detection, assessment and treatment technologies based on motion analysis [3], robotics [4], and rehabilitation fields [5], among others.

Motivated from the aforementioned perspectives, the principal objective of the ecosystem of the EC H2020 funded project i-PROGNOSIS (www.i-prognosis.eu) is the development of: (i) an ICT-based behavioral analysis approach for identifying, as early as possible, the PD symptoms appearance, and (ii) the application of ICT-based interventions countering identified risks.

To those identified and clinically validated as early stage PD patients, ICT-based interventions are provided via the i-PROGNOSIS Intervention Platform, including: (i) a Personalized Game Suite (ExerGames, DietaryGames, EmoGames, Handwriting/VoiceGames) for physical/emotional support, and (ii) assistive interventions for voice enhancement and gait rhythm guidance. Overall, i-PROGNOSIS leverages and extends the state-of-the-art in a number of different areas, such as behavioral, physiological and lifestyle monitoring, motion capture, physical activity evaluation, personalized gaming, home-based human-computer interfaces, multi-parametric data modelling and decision support systems, ensuring valuable intellectual property. In this vein, for the present study, part of the i-PROGNOSIS ecosystem is presented, namely the iPrognosis Games, along with the opinion/feedback of health and medical experts from the three collaborating medical centres of the i-PROGNOSIS consortium, in Greece (Aristotle University of Thessaloniki-Medical School, AUTH-MED), in Germany (Technischen Universität Dresden, TUD) and in the United Kingdom (King's College London, KCL).

2 THE iPROGNOSIS GAMES

Overall, the iPrognosis Games aim to monitor and support older adult's physical and emotional status enhancement, towards the decrease of the PD-related risks and increase of their QALYs. The iPrognosis Games application, an Android mobile application, already available on Google Play Store¹, consists of 14 different games, taking into account the PD symptoms (i.e., Exergames, Dietarygames, Emogames, Handwriting and Voicegames), constituting the Personalized Game Suite (PGS), along with the Warming up game and motor Assessment Tests. Moreover, the iPrognosis Games differ in the required equipment for playing them, that also defines different target uses; more specifically: i) Games requiring the MentorAge®² sensor device (four games) are targeting to be used inside specialised PD clinical centres or at home if the user purchases the sensor device, and ii) Games requiring a smartwatch or tablet (with microphone and frontal camera) (ten games) can be played either at home environment or be played under supervision in clinical settings.

2.1 Warm-up Game

The i-PROGNOSIS Games application includes a Warm-up Game (see Figure 1) that was developed with a dual purpose. Initially, this

¹ <https://play.google.com/store/apps/details?id=com.TeoS.iPGS&hl=en>

² <http://www.nively.com/en/>

Figure 1: Indicative example of the user interface of the i-PROGNOSIS Warm-up Game. (Top panel) Gaming session with one fixed virtual object (apple) for the patient to collect using hand movements. (Bottom panel) Game's static sequence of apple positions (green numbers: objects in front of the patient in the 3D space; red numbers: objects in parallel to the patient's).

game was designed in order to familiarize the user with the virtual environment and the gamification element in the intervention platform. Next, this game served as a real warming-up session designed to increase blood flow and oxygen to the main muscles, reducing the chance of soft tissue injuries (i.e., ligament, tendon and muscle), facilitating muscles and joints to move through a greater range of motions.

The Warming-up game scenario consisted of an avatar controlled by the players' body movements that were detected using a depth sensor. The patients could move their hands around freely to collect the apples that appear on their screen. For each appearing apple, players had a time window of 5 seconds to successfully catch it. Each game session consisted of a static sequence of nineteen positions where apples appear one after the other. For each successful try, players' score was boosted and positive auditory feedback was provided. After a player's performance was completed, an overall evaluation score was communicated, along with an appropriate feedback message.

In order to estimate the player's game performance, the time required to catch an apple for each position, the overall game duration, the failures and their score are recorded. In addition, during each gameplay, the RGB stream of the depth sensor was optionally captured and saved at 16fps, in order to be used for further motion data analysis. More detailed information can be found in [6].

Figure 2: (Top panel) PD patient performing the Leg Agility Test of the i-PROGNOSIS Motor Assessment Tool (iMAT). (Bottom) User interface of the Assessment Test 2 (Leg Agility). The user's and the expert's performance are compared in real-time side-by-side, and quantified through the level of agility agreement depicted in the score in the middle of the screen.

2.2 Motor Assessment Tool

Apart from the Warming up Exergame, in order to evaluate the effect

of the iPrognosis Games on the PD patient's status, the i-PROGNOSIS Motor Assessment Tool (iMAT) was constructed to complement the i-PROGNOSIS PGS (see section 2.3), and also creating the opportunity to deploy this component as a stand-alone assessment module. It is important to note that the motor aspects within iMAT are also reflected within the general design of the Exergames included in the i-PROGNOSIS Games. Thus, iMAT can be seen as a complement to PD patient's conventional motor status monitoring, but also it can be used as a tool for measuring the intervention's progress [7].

2.3 Personalized Game Suite

Finally, the i-PROGNOSIS Personalized Game Suite (PGS) includes a variation of Serious Games (SGs) in a unified and personalized platform for PD symptoms management. The PGS consists of 14 different games, namely: three Exergames targeting whole-body motor symptomatology (i.e., Fishing, Picking Citrus Fruit, and Kinematic Orchestra), three Dietarygames targeting improvements in dietary characteristics (i.e., Eatwell Plate, Sudoku and Retrain Eating Behaviour), two Emotional games targeting

Figure 3: Indicative example of the user interface of the iPrognosis Game selection. (Top panel) Sub-categories of the Personalised Game Suite, and (Middle and bottom panels): Available games in each sub-category.

emotional symptomatology aspects (i.e., Face Rhapsody and Imitation game), three Handwriting games for training finger fine-motor skills (i.e., Driving, Find me, and Writing letters) and three Voice games for the improvement of speech characteristics (i.e., Catching Voicimons, Pop the balloons and Good night story) (see Figure 3).

Moreover, the developed battery of 14 interventional and quality-of-life improving Games are based on the following PD targeted symptomatology:

1. Motor-improvement (six games): posture, gait, postural instability, fine motor skills impairment and tremor;
2. Non-motor Improvement (five games): facial expression/depression and constipation; and
3. Speech-improvement (three games): voice and speech difficulties.

Tackling the most often appearing PD symptoms via the gamification concept, iPrognosis Games can provide a user-friendly environment with bilateral functionality, i.e., both engaging the user into long-lasting supportive activities, which could retard the evolution of the symptoms, and providing to the physician, the necessary information for monitoring the PD patient's status in a quantitative and detailed way.

The iPrognosis Games differ in the required equipment for playing them, that also defines different target uses; more specifically: i) Games requiring the MentorAge®³ sensor device (four games) are targeting to be used inside specialised PD clinical centres or at home if the user purchases the sensor device (~€700), and ii) Games requiring a smartwatch or tablet (with microphone and frontal camera) (ten games) can be played either at home environment or be played under supervision in clinical settings.

Table 1. Basic characteristics of the PD patients included in the intervention data sample across the three i-PROGNOSIS medical centres

Clinical Centre	Female	Male	Total	Age (years); mean (st.dev)
AUTH	2	11	13	65.5 (8.9)
KCL	7	5	12	58.5 (8.8)
TUD	5	6	11	65.7 (10.3)
	14	22	36	63.2 (9.7)

More detailed information about the design and development of the games can be found in [8]-[13].

2.1 Intervention Protocol

The i-PROGNOSIS interventional data feasibility study included 36 PD patients spread across the three clinical sites of the i-PROGNOSIS project, i.e., AUTH-MED), in Germany (TUD) and in the United Kingdom (KCL). The PD patients were recruited and participated in the study from September 2019 to January 2020. Table 1 presents the basic characteristics of the study sample and their distribution among the three clinical centres.

The protocol included periodic sessions (one per month) of the iPrognosis Assessment Tests under the controlled environment at the three medical centres. The PD patients could perform each Assessment Test up to four times per session. At the beginning of each session of the Assessment Tests, an exercise game (Warm-up Exergame), was first performed by the PD patients, mainly to provide the PD patient with an initial contact with the sensor device and related environment and to gradually increase their heart rate and body temperature, including general coordination activities to prepare the PD patients for the preceding Assessment Tests.

At the same time, all PD patients were motivated to engage with every category of games, according to their availability and participant's willingness, but they were motivated to focus on the specific groups of games and follow the medical protocol based on the specific set of symptoms of the PD patient. In addition, each medical center involved in the present study was equipped with the depth sensor tracking system Mentorage® and assisted with technical support. Overall, the PD patients were able to perform the iPrognosis Warm-up game, the motor Assessment Tests and the PGS by moving in front of the MentorAge® sensor, placed at least 1.5 meters in front of it, as it can be seen in Figure 2. The acquired data were de-identified and securely stored in the backend database of the i-PROGNOSIS.

3 METHODOLOGY

A largely influential report by Wyatt and colleagues [14] sets the aims of medical evaluation of novel medical informational systems based on three main questions:

³ <http://www.nively.com/en/>

*Are they effective?
Are they safe?*

Do they change the use of health care resources?

Indeed, this basic framework has since resulted in formative efforts of evaluating the real-world medical value of novel informational medical platforms, including both systems for optimal use of existing resources (e.g., Electronic Health Records [15]) and novel diagnostic [16], monitoring [17] and interventional [18] systems for a variety of diseases and medical conditions. In many of the above examples, the medical expert evaluation processes place the medical and clinical experts' opinions for a system's performance as the central point of reference. Understandably, these user groups are the eventual mediators for the widespread adoption of such systems within the pre-medical and medical practices, having the potential of reducing the, typically long [19], adoption periods for translational and methodological innovations.

A more systematic assessment of medical expert evaluations [20] sets three potential purposes for the evaluation process, namely focusing on: i) comparing the results with the goals and the expected effects of a novel system, ii) directing further development work towards the expected result, and iii) using the findings and outcomes of the evaluation process as an experience base for the next round of development. However, past experiences point towards various methodological difficulties when innovative informational medical systems are being evaluated. Such issues mainly arise due to [20]: a) the innate complexity of modern informational platforms, making it difficult for the medical expert to evaluate the methodological nuances of the innovative approach, and b) unfeasibility of proper randomised and blinded medical system evaluation protocol, due to the, often, lack of comparable traditional medical evaluations and processes.

Nevertheless, the need to evaluate medical systems, despite the difficulties, is often emphasized [21], stating the central role of collecting valid expert feedback through careful and proper analysis and presentation of system components and outcomes to the target user and expert groups [22].

3.1 Data collection

Methodologically, for the formulation of the "Expert Evaluation Form" regarding the i-PROGNOSIS interventions (see Figure 4), the existing knowledge and literature-based framework presented in previous section was considered. Initial efforts towards this end were focused on identifying pre-existing questionnaires and evaluation frameworks for evaluations of novel medical informational and decision-support systems that would be appropriate for the i-PROGNOSIS framework. However, due to the system-specific characteristics and the innovative nature of the i-PROGNOSIS effort, the above task has not been possible. Indeed, the difficulties for the creation of proper, all-encompassing evaluation frameworks for existing decision-support systems have been identified many times (e.g., [23]) this was a challenging task. Thus, the i-PROGNOSIS project has opted for the creation of a

The figure shows four panels of the 'i-PROGNOSIS' medical expert evaluation form. The top-left panel is the title page 'Medical Expert evaluation form'. The top-right panel, titled 'Interventions', describes the system's goals and target users. The bottom-left panel contains evaluation questions about the system's use and potential. The bottom-right panel contains questions about the system's advantages and challenges.

Figure 4: Medical Expert evaluation Form regarding the i-PROGNOSIS interventions.

custom, need-focused expert evaluation form (with some inspiration from contemporary similar efforts [24]). The final format of the Expert Evaluation Form regarding the i-PROGNOSIS interventions can be found in Figure 4.

3.2 Data analysis

The analysis of the collected expert feedback was performed using traditional qualitative analysis techniques, focusing on the descriptive analysis of the results, in order to evaluate the overall attitudes of the experts towards the i-PROGNOSIS' achievements. Specifically, all the ordinal evaluation questions were descriptively analysed, based on the ranges of the collected responses [25]. Thus, for the provided seven-step evaluation inquiries, answers were coded from 1 to 7 and the responses within the 0-2 were ranked as "Strong disagreement", answers coded as 3-5 were rated as "Neutral opinion" and 6-7 answers were coded as "Strong agreement".

Similarly, *thematic analysis* was used for the analysis of the free-text answer, where content analysis of each provided answer was performed [26]. To achieve that, a matrix of open codes per item was created, in order to support code repetition analysis [27]. In summary, each provided answer was contextually analysed and repeated common concepts were quantified. Finally, the frequency rates for contextually independent concepts, within the overall pool of quantified concept-mentions, were calculated. The results are

Table 2. Descriptive characteristics of the responders that provided feedback through the Expert Evaluation Forms

Clinical Centre	Experts (n)	Average Clinical Experience (yrs) in PD
TUD	3	7.0
KCL	5	7.0
AUTH	10	6.4

presented in the following subsection in the form of ranked concepts mentioned, sorted from the most frequent to the least common ones.

4 RESULTS AND DISCUSSION

After reaching out to the clinical network of the i-PROGNOSIS clinical partners (AUTH-MED, TUD, and KCL), 18 Expert Evaluation Forms were collected. The sample included clinicians with hands-on experience with the i-PROGNOSIS platform (n=15), as well as a limited number of “innocent” responders (n=3) without prior i-PROGNOSIS experience. All the respondents had significant clinical experience in providing health care for PD populations (mean years of experience: 6.2), while a significant proportion of the respondents (n=11), also had experience from clinical and medical research in the field of PD development, intervention and management. The descriptive characteristics of the respondent sample can be seen in Table 2.

The Expert Evaluation Form was focused on collecting feedback from the i-PROGNOSIS expert network concerning the potential of the intervention data system module that concerns the development and the deployment of the i-PROGNOSIS Interventions through 14 interventional and quality-of-life improving SGs. These were grouped into three main categories based on the types of targeted symptomatology:

1. Motor-improvements (6 games),
2. Non-motor improvements (5 games), and
3. Speech-improvement (3 games).

Specifically, during the distribution of the evaluation form (January 2020) the data collection was ongoing, with the i-PROGNOSIS project having decided that the Intervention deployment would have the nature of a *feasibility trial*, rather than a long-term monitoring trial. Thus, this prohibited the evaluation of this system module based on quantified quality-of-life improvements. Similarly, the clinical effects of the games could not be properly evaluated and communicated to the experts. Instead, the experts were provided with a preliminary analysis of user evaluations (based on the data included in the collected *CFIII forms* in the OpenClinica platform⁴). Based on the provided user evaluations and the experts' own experience with the intervention data system, the collected respondent opinions were *fairly positive* for the potential of the intervention data system to add value to existing clinical interventions in *Specialised* and *Primary/Outpatient* Care.

Table 3. Frequency analysis of the expert opinions with regards to the i-PROGNOSIS Intervention system

Strong disagreement	Neutral opinion	Strong Agreement
<i>Question 1: The i-PROGNOSIS system has the potential to add value to existing clinical interventions provided by specialised PD centres (n=18)</i>		
0.0%	33.3%	66.7%
<i>Question 2: The i-PROGNOSIS system has the potential to add value to existing clinical interventions provided by primary care centres and/or outpatient care providers (n=18)</i>		
0.0%	22.2%	77.8%
<i>Question 3: The i-PROGNOSIS system has the potential to add value to existing clinical interventions, through patient self-monitoring of disease progression (n=18)</i>		
5.6%	33.3%	61.1%
<i>Question 4: The i-PROGNOSIS system could be intergraded with current patient monitoring and support systems (n=17)</i>		
5.9%	11.8%	82.4%

In general, the experts' opinions were also *fairly positive* for the self-monitoring and integration potential of the system to current monitoring and support systems, despite a small segment of the sample that was negative. The results can be seen in Table 3. In addition, overall percentages of strong agreement among the respondents are presented in Figure 5.

Overall, the results are positive, despite the comparatively immature state of deployment and evaluation process. These results create optimism about the clinical value of the developed system once the evaluation efforts are expanded and properly disseminated among the medical community (beyond the lifecycle of the i-PROGNOSIS project).

The experts also evaluated the three (3) *main advantages* of the developed Interventions data module with regards to its value as a quality-of-life improving tool throughout the PD development (see Table 4). Their feedback mainly focused on the *accessibility of the system* for patients and clinicians and the *attractive* aspect of the game design that has the potential to *promote longer-term use*. Another frequently mentioned point was the fact that the platform facilitated *self-monitoring of the disease*, often conceptually connected with the *increase of patient self-awareness* about the progress of the monitored symptoms.

With regards to the main *challenges* for the use of the Interventions data module as a tool for improving quality-of-life, PD monitoring and interventions throughout the PD development, the experts emphasized the need for further *optimisation in the design*, the *functionality*, the *feedback to the patients* and the *technical*

⁴ www.openclinica.com

Figure 5: Percentage of strong expert agreement for the potential of the i-PROGNOSIS system characteristics.

Table 4. The main advantages of the i-PROGNOSIS module, as identified by 17 medical experts

Identified i-PROGNOSIS system advantages	Mentions	% of Experts*
Attractive design.	12	71%
Accessible to patients despite age group.	11	65%
Facilitates self-monitoring of the disease progress.	7	41%
Has the potential for long-term disease monitoring	6	35%
It targets the full range of clinically significant PD symptomatology.	6	35%
It can be (partly) deployed in the home environment.	5	29%
It targets at improving quality of life for PD patients.	5	29%
It promotes self-awareness in PD patients regarding symptomatology progression.	5	29%
It has high potential for use in other relevant medical fields.	3	18%
The games have a desirable social element.	2	12%
The platform is innovative.	2	12%
The integrated progressive reward system improved compliance.	2	12%
It promotes exercise and increased physical activity for patients.	2	12%

*at least one mention per subject

integration of the platform, in order to support longer-term use (see Table 5). Also, the respondents pointed the need for long term feasibility trials to evaluate the compliance of use and the effects of the games on the disease state of the patients. Towards such recommendations, upon the completion of the i-PROGNOSIS

Table 5. The main challenges for the adoption of the i-PROGNOSIS module as an intervention and patient monitoring system, as identified by 18 medical experts

Identified i-PROGNOSIS challenges	Mentions	% of Experts*
Fine tuning of the interfaces and the functionality is required.	8	44%
The innovative nature of the platform requires initial effort to convince patients to use the system.	5	28%
A long-term feasibility trial for the evaluation of the compliance of use is needed.	4	22%
Technical improvements are required.	3	17%
The patient directed feedback needs to be optimised.	3	17%
The system effects on PD symptomatology during long term use should be validated.	3	17%
More flexibility when patients select the initial game difficulty is required.	2	11%
Specialised equipment (partly) is needed for clinical deployment.	2	11%
The emotional state of patients might be a hinder for long-term use.	2	11%
More games might be required for additional symptoms and added variety might be needed.	2	11%
Users' data privacy concerns.	1	6%
Integration with current Health Care Systems and Records will be challenging.	1	6%
iOS support is required for the mobile/tablet-based games.	1	6%

*at least one mention per subject

project, technical refinement and increased patient participation were achieved in four-month feasibility study.

5 CONCLUSIONS

The i-PROGNOSIS system is well on its way to provide interventional tools, such as the iPrognosis Games and the iMAT, for complementing existing clinical practices for the management of PD symptomatology, always targeting the improvement of patients' quality of life. However, beyond the end of the i-PROGNOSIS project, key parameters should be taken in consideration, in order to ensure the wider adoption of the i-PROGNOSIS by the medical community.

In an effort to probe further, the evaluation of the level of the PD patient engagement with i-PROGNOSIS system will be taken into consideration, through the analysis of the monitored user-iPrognosis Game interaction.

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