Effects of Exergaming on Motor Performance in Parkinson’s Disease: A Pilot Study Using Azure Kinect

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Abstract. One of the most disabling features of Parkinson's disease is the impairment of motor function due to specific symptoms affecting different body districts. The most visible manifestations include slow movements (bradykinesia), gait disorders, balance disorders, postural changes, and complex control and coordination of body movements, especially as the disease progresses and symptoms worsen. Healthcare facilities traditionally employ targeted physiotherapy treatments to improve patients' motor conditions and increase their perceived safety and independence in daily activities. Despite the recognized benefits, these treatments are still underutilized in terms of time and accessibility because of the costs and resources involved. The paper presents an integrated solution to stimulate physical activity through exergames, i.e., exercises in a virtual game environment, and assess motor performance using specific standardized tasks. The new Azure Kinect DK camera and 3D non-contact body tracking libraries implement an easy-to-use vision system. A two-week, exergaming-based experimental protocol involving 12 patients in a healthcare facility was defined to evaluate its potential for future use in home environments. Preliminary results of the pilot study are presented and discussed.

Keywords: Azure Kinect, Exergaming, Automatic Assessment, Movement Analysis, Remote Monitoring, Motor Rehabilitation.

1 Introduction

Parkinson's disease (PD) is a debilitating condition that affects millions of individuals worldwide, with a prevalence of 1% in the population over 65 [1]. The pathology manifests through non-motor symptoms such as cognitive impairment, depression, and sleep disturbances but mainly with motor disabilities such as freezing of gait, bradykinesia (slow movements), dyskinesia and tremor at rest, that affect the patients' quality of life [2]. The use of traditional physiotherapy treatments and physical activity has been recognized as effective in improving motor function in individuals with PD [3]. However, accessibility and cost constraints limit the availability of these treatments, and innovative and cost-effective interventions are needed [4].

New technology such as the Azure Kinect DK camera and 3D non-contact body tracking libraries, adds a new dimension to the assessment and rehabilitation of motor performance in parkinsonian subjects. This technology provides clinicians with a non-invasive and precise way of measuring movement patterns and gait parameters [5,6], even in telemedicine and telerehabilitation scenarios. This may help in the development of personalized and targeted treatment, either pharmacological or rehabilitative.

Exergames, a novel approach to physical exercise combining videogames and physical activity, have emerged as a promising intervention to help individuals maintaining and improving their motor performance [7]. Such games provide an interactive and engaging virtual environment that can motivate patients to engage in physical activity and offer a sense of enjoyment and accomplishment. All these aspects may increase adherence to exercise programs and continuity of use, which are fundamental for efficacy. Recent studies have highlighted the potential benefits of exergames in improving motor function and physical activity levels in elderly and individuals with PD [8]. Overall, the use of exergames in combination with new body tracking technologies offers a promising avenue for improving motor function and physical activity in individuals with PD. Moreover, these interventions provide a cost-effective and accessible solution that could be implemented in home environments with minimal supervision.

This paper reports the preliminary results of an innovative vision system based on Azure Kinect camera, which integrates both automatic assessment of motor performance and a suite of Exergames for rehabilitation of upper and lower limbs in Parkinson’s disease. Such vision system constitutes the Motor Rehabilitation and Exergames Platform (MREP) described in [9]. It was developed as part of the REHOME project [10], in which the consortium designed ad-hoc platforms for the monitoring and rehabilitation of motor and cognitive functions in individuals affected by neurological and neurodegenerative diseases, including Mild Cognitive Impairment, Parkinson's disease, and post-stroke conditions.

The paper is organized as follows: Section 2 describes the methodological approach, including a brief description of the acquisition system and exergames, the experimental protocol, and the data analysis; Section 3 presents the result of the experimental trials related to the analysis of patients’ performance and questionnaire answers; Section 4 discusses the overall results of the study, with strength and limitations, providing the direction for future improvements.

2 Materials and Methods

2.1 Characteristics of the vision system

The vision system used in MREP relies on the Microsoft Azure Kinect DK camera [11], released three years ago to replace the previously discontinued RGB-Depth models. The RGB-Depth technology, popularized with Kinect, has been widely used in motion analysis for several years due to the availability of non-invasive and non-contact 3D body tracking algorithms (BTA). The tracking algorithm available for Azure Kinect [12] exploits a combined methodological approach based on Deep Learning (DL) and Part Affinity Field (PAF) [13]. The latter makes it possible to localize, on a real body, 32 points that constitute a 2D skeletal model, which is subsequently augmented to 3D using depth information provided by the camera and predictive DL algorithms. Specifically, BTA version 1.0.1 [14] was used in this study.

To work in real-time, the BTA requires high computational resources: for this purpose, we used a ZOTAC© ZBOX EN52060-V, equipped with 16 GB RAM, NVIDIA GeForce RTX 2060 6GB GDDR6, and a 9th generation processor (quad-core 2.4 GHz). Regarding camera settings, we configured 1080p resolution for RGB stream, Narrow Field of View (NFV) mode for depth stream, and 30 fps for both. NFV mode allows us to detect bodies and capture movements farther from the camera and in a broader space, consequently facilitating interaction with the system through specially designed user interfaces. All motor tasks and exergames were performed facing the camera to ensure full body tracking and motion estimation accuracy [15].

2.2 Exergames and standardized assessment tasks

The main functionalities of MREP include motor condition assessment through tasks derived from clinical rating scales and motor rehabilitation/training through exergames in a virtual environment [16].

Although MREP includes many functionalities and sensors, only those sharing the RGB-Depth camera as the data acquisition device were investigated in this study: in this way, we did not overburden the experimental protocol, thus allowing patients to become familiar with one instrument at a time. In addition, since the study focused on subjects with PD, only some of the implemented assessment motor tasks were considered, specifically those derived from the UPDRS scale [17]. Among these, we also excluded the hand-specific ones: as described below, the exergames in the virtual environment aimed to stimulate specific body segments rather than fine hand movement.

Accordingly, the following assessment tasks and exergames were included in the experimental protocol [16,18] to stimulate different body motor functions and evaluate them objectively and automatically through specific functional parameters:

- Leg Agility (LA): UPDRS task to assess lower limb mobility (left and right leg). The patient was asked to perform repetitive movements of the leg for 15 seconds at maximum speed and amplitude;

- Sit To Stand (STS): UPDRS task to assess the patient’s lower limb strength and stability. The patient was asked to stand up from a chair in the shortest possible time and maintain an upright, stable position for 10 seconds;
- Postural Stability (PoS): UPDRS task to assess balance disorders. The patient was asked to maintain an upright position for 30 seconds;
- Gait (G): UPDRS task to assess abnormalities during walking. The patient was asked to walk 6 m at a comfortable speed;
- Lateral Weightlifting (LWL): gamified task in a virtual environment to assess upper limb mobility (left and right arm). The patient was asked to repeatedly lift the arm laterally, at maximum speed and amplitude, and perform a prefixed number of lifts. This task also includes a synchronous mode in which the patient was asked to lift both arms simultaneously (to emphasize the presence of arm asymmetry);
- Frontal Weightlifting (FWL): like LWL, but the lifts are performed frontally;
- Bouncing Ball (BB): gamified version in a virtual environment of LA. The patient was asked to hit the ball with the leg when a halo was visible (preconfigured speed);
- Cross-Country Skiing (CCS): exergame to stimulate alternating upper limb movements, coordination, and motor control. The patient was asked to perform continuous and rhythmic movements to guide a virtual skier and collect the highest number of objects (gems), completing the track in the shortest possible time;
- Airplane (PLANE): exergame to stimulate trunk movements and upper limb control. The patient was asked to perform continuous trunk movements, with arms extended laterally, to guide a virtual airplane on a flight path that includes colored rings and obstacles, crossing as many rings as possible in the shortest time;
- Keyboard (KEY): exergame to stimulate control of pointing and arm extension skills. The patient was asked to move a virtual hand on a keyboard with colored keys when they light up to complete the musical sequence in the shortest possible time.

The exergames (designed and developed by Synarea Consultants S.r.l., Turin, Italy), UPDRS and gamified tasks (designed and developed by Cnr-Ieiit, Turin, Italy) constitute the suite of games implemented according to the clinical guidelines to stimulate patients’ specific motor functions in a more engaging, exciting and fun environment, thus encouraging active and continuous participation, even in the long term. To this end, all gamified tasks and exergames include realistic scenarios and increasing difficulty levels to enhance engagement and stimulate patients to achieve new goals tailored to their motor skills.

In particular, several elements were considered during the design phase of the exergames and gamified tasks to enhance patient engagement and experience. For example, game scenarios, environmental styles, and avatars suited to the stimulated movement, thus allowing the patient to immediately step into the scene and identify with the virtual character. In addition, using the body to move avatars without aids or other external devices encourages simple, active, and autonomous participation, providing immediate visual feedback of interaction with the game environment. Appropriate sounds and music enrich each game, increasing the patient's emotional involvement. Graphically, the size and shape of the objects in the game environments facilitate their identification and recognition. The system automatically repositions user interface interaction elements (game activation buttons, selection menus) according to the best-performing body side to facilitate the interaction without undue effort. Text and voice messages (text-to-speech functions) complement the user interface and guide the patient in completing tasks/levels.

Another feature common to all exergames and gamified tasks is the adaptability to the patient's motor condition and progress over time. To this end, we incorporated gamification elements to reward performance and encourage continuity of treatment over the medium to long term. Examples of gamification techniques include point rewards, timed challenges, and additional levels with increasing difficulty (e.g., more complex tracks, longer movement sequences, larger or more complex movements required). In addition, each game includes aspects related to attention and memory to stimulate the patient also through cognitive stimuli. All these elements aimed to improve user engagement, game experience, and satisfaction, as then revealed by the questionnaire administered to all participants at the end of the experimental protocol. Fig. 1 shows a patient engaged in the CCS and PLANE exergames under the supervision of healthcare personnel. The patient interacts autonomously with the game and its avatar.

Fig. 1. Example of patient's engagement in CCS (left) and PLANE (right) exergames.

2.3 Participants and experimental protocol

For this study, 12 PD subjects were recruited from the Division of Neurology and Neurorehabilitation at San Giuseppe Hospital (Istituto Auxologico Italiano, Piancavallo, Verbania, Italy). Only subjects with mild-to-moderate severity (Hohen & Yahr score <= 3) were included in the study, representing the target population for home use of the implemented solution. Subjects with more severe conditions (Hohen and Yahr > 3), excessive or permanent tremors, or cognitive deficits (Mini-Mental State Examination < 27/30) were excluded. The local ethics committee approved the study, and all participants signed informed consent. The experimental protocol was structured as follows:

- Training sessions: preliminary trials to familiarize with the system, tasks, and exergames after being instructed by healthcare professionals;
- T0: instrumental assessment of the basal motor condition (LA, S2S, PoS, and G);
- R1-R6: rehabilitation program (two weeks, sessions on Monday, Wednesday, and Friday) with exergames (CCS, PLANE, and KEY) and gamified tasks (LWL, FWL, and BB);
- T1: instrumental assessment of the final motor condition (LA, S2S, PoS, and G);
- Q: questionnaire administration.

The motor condition of each participant was clinically assessed a few days before T0 and a few days after T1. The complete motor examination (section 3 of UPDRS) was administered, thus determining the total UPDRS score before and after the experimental protocol.

The first instrumental assessment (T0) was performed concurrently with R1 before the patient started the rehabilitation session. The last instrumental assessment (T1) occurred with R6, at the end of the rehabilitation session. The experimental protocol included a maximum break of 2 minutes between exercises to allow the patient to recover from fatigue. If the patient was too fatigued, the operator supervising the session could stop the current session. All participants performed the experimental protocol under the same environmental conditions, under the supervision of a healthcare professional, and with a maximum involvement of 45 minutes.

At the end of the rehabilitation program, a simplified system questionnaire was administered to each participant to obtain concrete feedback on the user experience. The following categories were covered: Participant's technological skill (e.g., habitual use of computers and technologies); System's usability (e.g., ease of interaction, ability to meet needs); System's accessibility (e.g., readability and immediate understanding of user guidance instructions); Participant's overall satisfaction (e.g., user's overall judgment on system use and usefulness of the protocol). Three possible answers were available for each category to be clear and easily understood. Fig. 2 schematizes the experimental protocol.

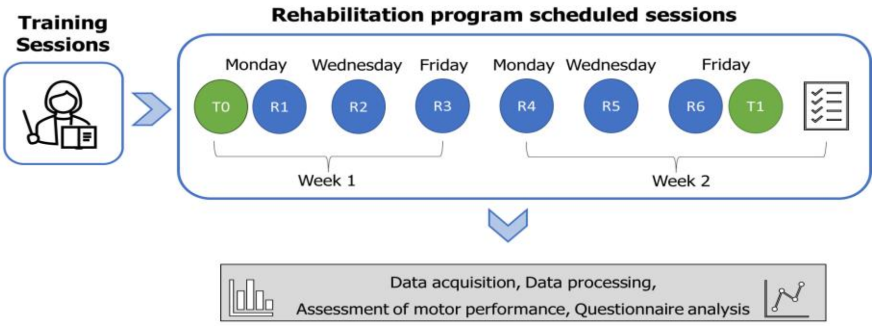

Fig. 2. Schema of the experimental protocol.

2.4 Analysis of motor performance

The instrumental assessment of motor performance (LA, S2S, PoS, and G) relied on the objective measurement of specific functional parameters estimated from the 3D movement trajectories captured by the vision system: few parameters were identified to represent the main characteristics of each assessment task.

For the LA task, the following parameters were considered: maximum leg lift angle (MLA_{LA}), duration of movement (D_{LA}), and speed of movement (S_{LA}). They were averaged for all movements performed with both legs. For the S2S task, the following parameters were considered: maximum trunk bending angle (MBA_{S2S}), duration of movement (D_{S2S}), and speed of movement (S_{S2S}). They were estimated from the start of movement to the final stable standing position. For the PoS task, the following parameters were considered: total anteroposterior (APT_{PoS}) and mediolateral (MLT_{PoS}) sways. They were estimated from the initial upright position. For the G task, some traditional spatiotemporal parameters were considered: cadence (CAD_G), step length (SL_G), gait speed (S_G), and stance percentage (ST_G). They were average for both legs.

Only a few game parameters were considered for exergames, including time to complete the level (T_{CCS}, T_{PLANE}, and T_{KEY}), number of points (PT_{CCS}, PT_{PLANE}, and PT_{KEY}), and errors (E_{CCS}, E_{PLANE}, and E_{KEY}). Currently, no parameter was estimated for gamified tasks, which were only used to engage patients in other exercises and increase motor stimulation.

The estimated parameters were analyzed (T0 vs. T1) considering intra-group and intra-patient comparisons to extrapolate general and personalized considerations on the exergaming-based rehabilitation program.

3 Experimental Results

3.1 Patients and data acquisition

The demographic and clinical characteristics of the patients involved in the study were: 12 subjects (7 males); 76.1±6.1 years (average age); 6.4±4.0 years from PD diagnosis; 29.1±12.7 points (average UPDRS total score); 2.8±1.9 points (average Hohen & Yahr total score).

All the participants were able to complete the rehabilitation program. However, a few participants could not always perform assessment tasks, gamified tasks, or exergames due to their clinical condition and health status on the day of the scheduled session, leading to partial or skipped sessions. The percentage breakdown for assessment sessions (T0 and T1) was 95.8% (complete) and 4.2% (partial); for rehabilitation sessions (R1-R6) was 88.9% (complete), 6.9% (partial), and 4.2% (skipped), respectively; for questionnaire sessions (Q) was 100.0% (complete).

3.2 Analysis of the motor performance

The intra-group analysis included the parameters of all the patients (aggregate data), estimating the mean and standard deviation to compare T0 and T1. In contrast, in the intra-patient analysis, the comparison (T1 versus T0) was based directly on the parameters of each subject (point data), estimating the percentage variation.

The average clinical UPDRS total score changed from 28.83±4.71 (T0) to 27.17±6.37 (T1). This result denotes a slight reduction in the overall score but an increase in the intra-group variability. However, it is essential to note that the complete UPDRS assessment includes motor tasks not specifically stressed by the exergaming-based rehabilitation program, including hand and foot mobility, for which the UPDRS scale defines dedicated assessment items.

Regarding the intra-group analysis, Table 1 shows the parameters estimated for assessment tasks and exergames (average on all participants).

Table 1. Intra-group analysis between T0 and T1 (aggregate data).

Task/Exergame	Parameter (unit)	T0	T1
LA	MLA_{LA} (deg)	32.53±13.26	29.81±13.28
	D_{LA} (s)	0.93±0.27	0.97±0.40
	S_{LA} (deg/s)	73.49±23.47	79.44±42.27
S2S	MBA_{S2S} (deg)	33.34±12.03	30.02±9.83
	D_{S2S} (s)	2.92±1.67	2.54±1.63
	S_{S2S} (deg/s)	27.84±13.38	27.05±10.58
PoS	APT_{PoS} (mm)	36.05±15.24	39.12±20.42
	MLT_{PoS} (mm)	20.78±7.45	22.62±11.39
G	CAD_{G} (step/min)	107.48±18.22	102.74±13.69
	SL_{G} (m)	0.52±0.08	0.52±0.11
	S_{G} (m/s)	0.83±0.16	0.82±0.23
	ST_{G} (% gait cycle)	65.75±4.96	66.24±9.63
CCS	T_{CCS} (s)	338.78±139.25	335.92±244.75
	P_{CCS} (#)	1.73±3.38	3.58±3.63
	E_{CCS} (#)	10.64±10.62	6.25±7.65
PLANE	T_{PLANE} (s)	51.72±8.61	51.49±8.71
	P_{PLANE} (#)	2.42±2.11	3.58±2.54
	E_{PLANE} (#)	0.00±0.00	0.00±0.00
KEY	T_{KEY} (s)	30.87±5.78	21.27±4.57
	P_{KEY} (#)	4.58±1.44	4.75±0.87
	E_{KEY} (#)	4.67±3.34	4.00±5.03

Focusing on the assessment tasks (LA, S2S, PoS, and G), there is no evidence of a general improvement at the group-level: most parameters appear to be reasonably stable. This behavior aligns with the mentioned slight improvement in the UPDRS clinical assessment. In addition, the increase in standard deviation confirms more variability in T1 as occurs for UPDRS score: this could mean that some subjects improve their performance while others worsen it.

In contrast, the improvement is quite evident for the exergames. In the most challenging exergame (CCS), the time to complete the level slightly decreases in T1 (with increased variability), the number of points increases, and the errors decrease: this denotes an overall better motor control (alternating arm movements) of the virtual skier and the widespread effort to obtain more points. The overall improvement in PLANE is appreciable by considering the higher number of points (more colored rings crossed) in T1. Once again, this denotes improvement in motor control (trunk movements) of the virtual airplane on the route. In contrast, T_{PLANE} is practically the same because this is approximately the time to complete the game level. Finally, the improvement in KEY is noticeable in time and errors, the latter related to incorrect keys pressed.

Another proof of the general improvement in exergames concerns the number of uncompleted trials: sometimes, patients could not complete the game level in one or more exergames due to clinical conditions or excessive fatigue (especially for CCS). The analysis shows that the percentage of correctly completed exergames was 94.4%, 78.6%, and 79.3% for KEY, PLANE, and CCS, respectively. Most uncompleted sessions were concentrated in the first part of the rehabilitation program, indicating progressive familiarization with the exergames and improved movements. The overall improvement in the use of exergames is also appreciable from the intra-patient analysis. As an example, the results concerning four patients are reported (Table 2) by comparing the first (R1) and the last (R6) sessions.

Table 2. Intra-patient comparison between R1 and R6 sessions.

ID	Exergame	Parameter	R1	R6	Considerations
PK5	CCS	T_{CCS} (sec)	281.28	308.64	PK5 took longer to complete the level (+9.7%), collecting more points (+600.0%) and with fewer errors (-47.4%)
		P_{CCS} (#)	1	7	
		E_{CCS} (#)	19	10	
	PLANE	T_{PLANE} (s)	51.95	51.24	PK5 took about the same time to complete the level (-1.4%), with no errors and collecting more points +100.0%)
		P_{PLANE} (#)	2	4	
		E_{PLANE} (#)	0	0	
	KEY	T_{KET} (s)	32.29	15.25	PK5 took less time to complete the level (-52.8%) without errors. Points (5) were the maximum possible for the game level.
		P_{KEY} (#)	5	5	
		E_{KEY} (#)	9	0	
PK6	CCS	T_{CCS} (sec)	365.75	380.26	PK6 took longer to complete the level (+4.0%), collecting more points (+200.0%) but with more errors (+11.1%)
		P_{CCS} (#)	1	3	
		E_{CCS} (#)	18	20	
	PLANE	T_{PLANE} (s)	36.11	53.83	PK6 was not able to complete R1 (lower time). PK6 correctly completed R6, collecting more points (+200.0%)
		P_{PLANE} (#)	2	6	
		E_{PLANE} (#)	0	0	
	KEY	T_{KET} (s)	22.80	22.75	Performance was quite similar in R1 and R6
		P_{KEY} (#)	5	5	
		E_{KEY} (#)	0	1	

PK7	CCS	T_{CCS} (sec)	410.37	851.17	PK7 doubled the time to complete the level (+107.4%), collecting all available points (10) without errors
		P_{CCS} (#)	9	10	
		E_{CCS} (#)	2	0	
	PLANE	T_{PLANE} (s)	55.04	54.99	Performance was quite similar in R1 and R6
		P_{PLANE} (#)	5	5	
		E_{PLANE} (#)	0	0	
	KEY	T_{KET} (s)	35.92	14.58	PK7 halved the time to complete the level (-59.4%), collecting all the available points with only one error
		P_{KEY} (#)	5	5	
		E_{KEY} (#)	1	1	
PK11	CCS	T_{CCS} (sec)	153.07	122.18	PK11 took less time to complete the level (-20.2%) without collecting points in both sessions
		P_{CCS} (#)	0	0	
		E_{CCS} (#)	2	2	
	PLANE	T_{PLANE} (s)	44.25	55.46	PK11 was not able to complete R1 (lower time). PK11 correctly completed R6 without collecting points
		P_{PLANE} (#)	2	0	
		E_{PLANE} (#)	0	0	
	KEY	T_{KET} (s)	23.15	23.97	Performance was quite similar in R1 and R6
		P_{KEY} (#)	5	5	
		E_{KEY} (#)	2	1	

Although the improvement in exergames is appreciable for all patients, albeit in different ways, the same is not equally evident in the instrumental assessment tasks and UPDRS clinical assessment. Table 3 reports the percentage variation (T1 versus T0) in the instrumental parameters and clinical assessment for the same patients. Changes in the UPDRS total score are partially reflected in the instrumental assessment.

Table 3. Intra-patient comparison between T1 and T0 (percentage variation)[1].

ID	UPDRS	MLA_{LA}	D_{LA}	S_{LA}	MBA_{S2S}	D_{S2S}	S_{S2S}	APT_{PoS}	MLT_{PoS}	CAD_{G}	SL_{G}	S_{G}	ST_{G}
PK5	11.1	21.9	2.1	27.2	-18.3	7.9	5.1	30.1	31.8	-1.9	-16.3	-22.2	6.8
PK6	3.2	7.0	36.4	-34.8	-19.4	21.4	-3.3	-32.8	-31.5	-4.5	-3.5	-9.6	1.9
PK7	-7.4	-45.9	-47.5	0.8	-30.6	-13.0	-10.3	98.7	7.2	-0.8	2.5	2.0	-2.4
PK11	-15.2	-0.7	-30.9	83.9	-3.0	37.0	-15.0	-29.7	-34.1	2.1	1.4	-0.1	0.0

[1]Cells with a red background indicate a parameter worsening in T1; green cells indicate a parameter improvement in T1; yellow cells indicate a minimal variation (< 1% in absolute value) in T1.

Patient PK5 shows the greatest worsening in UPDRS total score (T1>T0). The percentage changes indicate a significant worsening in PoS (increased sway in both directions) and G (high decrease in cadence, step length, gait speed, and increase in stance phase). Only partial worsening is observable in LA and S2S (higher duration).

Patient PK6 shows a slight worsening in UPDRS total score. The percentage changes highlight a significant worsening in G (decrease in cadence, step length, gait speed, and increase in stance phase); a significant improvement in PoS (decrease in both sways); a partial worsening in LA and S2S (higher duration and lower speed).

Patient PK7 shows a slight improvement in UPDRS total score (T1<T0). The percentage changes indicate a significant improvement in G (higher step length and speed, lower stance phase); a partial improvement in LA (in duration and speed) and in S2S (in duration). Only PoS significantly gets worse, thus indicating higher instability during standing. Finally, patient PK11 shows the most remarkable improvement in UPDRS total score. The percentage changes indicate a significant improvement in G (higher cadence and step length), PoS (lower body sways), and LA (higher speed and lower duration). Only S2S partially gets worse in speed and duration.

These results confirm that not all patients responded equally to the exergaming-based experimental protocol. Probably, a more extended period is needed to quantify and appreciate the benefits of exergaming through the assessment tasks. However, the results obtained are encouraging because the trend observed with the assessment tasks agrees with the trend assessed by clinicians.

3.3 Analysis of questionnaire responses

All participants (100%) expressed positive ratings on both system's accessibility and overall satisfaction (user experience) regarding the exergaming rehabilitation program. Fig. 3 shows the percentage breakdown of responses for the technological skills and system's usability categories.

A significant proportion of participants was almost devoid of habits in using technologies and skills (57%). Almost all participants (99%) indicated medium to high overall system usability. However, a significant proportion (70%) leaned toward medium usability, mainly suggesting the need to further simplify some preliminary steps before starting the exercise, as revealed by feedback from some participants.

However, this limitation could be overcome with more in-depth preliminary training that would give subjects more confidence and autonomy in using the system.

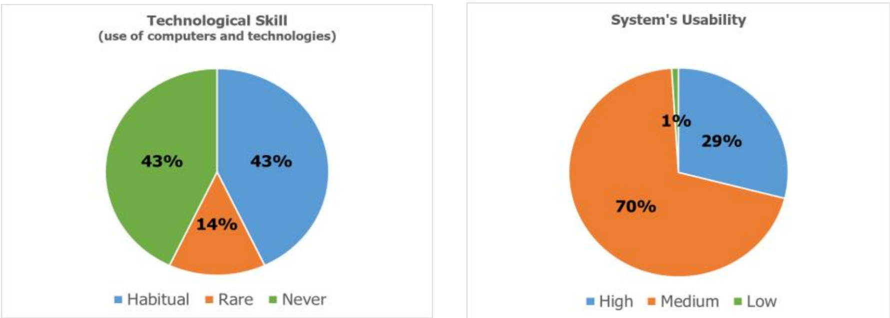

Fig. 3. Pie charts related to patients' technological skill (left) and system's usability (right).

Despite these aspects, the high overall satisfaction confirms the participants' significant interest, engagement, and enjoyment in going through the exergaming rehabilitation program, which demonstrated its feasibility and suitability for prolonged use, i.e., multiple daily sessions for several consecutive weeks.

4 Discussions and Conclusions

The paper presented a vision system based on the new Azure Kinect RGB-Depth camera for deploying exergames and gamified motor tasks to stimulate motor functions in subjects with Parkinson's disease. A pilot study was organized to test the feasibility of a short-term (two weeks) exergaming-based rehabilitation program.

The intra-group analysis shows only a slight decrease clinical assessment (UPDRS total score in T1). The instrumental parameters in T1 confirm the same trend, with only slight changes at the group level. In contrast, exergames parameters show a general and significant improvement in time, points, and errors. This result was expected since each patient responds differently to a treatment based on peculiarities and general health conditions. Intra-patient analysis indicated the same: although all patients showed improvement in exergames, improvement in assessment tasks was appreciable only in some patients and a few parameters/tasks. However, this was in line with UPDRS clinical scores.

It would probably be necessary to define longer (more weeks) and more intense (more times a day)/subject-tailored, exergaming-based rehabilitation programs to detect and appreciate overall improvement in motor performance. This limitation of the current study will be addressed in a future, larger clinical trial. Nevertheless, the questionnaire results also confirm the positive rating regarding usability (although some interface simplifications are needed), acceptability, and satisfaction, thus confirming the effectiveness of an exergaming-based protocol in terms of engagement and enjoyment.

These results are therefore encouraging and seem to support the feasibility of the protocol, with proper adjustments, to deploy motor tasks and exercises in home settings.

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