SI-ROBOTICS System: a preliminary study on usability of a rehabilitation program in patients with Parkinson’s disease

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Abstract

In this paper, SI-ROBOTICS, a rehabilitation programme for people with Parkinson's disease, is presented along with preliminary results. The SI-ROBOTICS system, consisting of a robotic platform, a game, wearable and environmental sensors, and an artificial intelligence algorithm, aims to sup-port the treatment of Parkinson's patients following a rehabilitation programme based on Irish dance practice. Nine patients were recruited in the study and underwent 16 sessions of the programme. The primary objective of the study was to evaluate the usability of the system. Secondly, the bene-fits in terms of improved walking, balance and reduced risk of falls were evaluated. Preliminary results suggest that the system has a good chance of success, as it was found to be usable and effective in treating conditions typical of Parkinson's disease.

Keywords

social robotics, Parkinson’s disease, rehabilitation, Irish dancing, balance, gait, technological approach

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1. Introduction

Parkinson's disease (PD) is one of the most common causes of disability among older persons [1]. It is a chronic-neurodegenerative disease that progresses with time, characterized by motor disorders, in particular bradykinesia (poor and slow movement), rigidity, postural instability and shuffling gait which, in the advanced stage, lead to a deficit of balance and thus a higher risk of falling [2]. In fact, postural instability is one of the cardinal signs in PD and can be present even at diagnosis, but becomes more prevalent and worsens with disease progression [3]. These pathological conditions are routinely treated by rehabilitation approaches aimed at improving static/dynamic balance, recovering walking ability and preventing falls [4, 5].

Recently, new non-pharmacological interventions are being studied to improve balance and to recover the normal gait of patients with PD. These include rhythmic auditory stimulation, using sounds at different rhythms, walking on walkways, leg alternating exercises, and performing functional tasks, which can be personalized treatments and easy to understand. In addition, another useful method for rehabilitating balance in the early stages of the disease is the use of dance [6]. It has been shown that dance in people with PD can have a positive effect on balance and mobility and can help improve quality of life by reducing symptoms of depression [7-10]. In particular, Irish dancing, along with tango and different forms of modern dance, may be a valid tool to motivate people with PD to perform physical activity. Recent studies have shown that Irish dancing can improve balance, mobility and quality of life through the integration of complex learning patterns of motor skills, dynamic balance, musicality and socialization [11-14]. In addition, Irish music, due to its rhythm, has a predictable pattern that can improve gait and walking.

In the light of what has been said, the present protocol aims to implement a rehabilitation program based on a new system called "SI-ROBOTICS", composed of multiple technological components, such as a robotic platform, the game, environmental and wearable sensors, AI reasoner and an artificial vision setting. The objective is to facilitate a rehabilitation program based on Irish dancing, to help the patient perform the dance steps and to collect kinematic and performance parameters that will be used both by the physiotherapist for the evaluation and planning of the subsequent sessions, and by the system to outline the levels of difficulty of the exercise. The system is developed and tested under the Italian national collaborative project SI-ROBOTICS “Healthy and active aging through SocIal ROBOTICS” (ARS01_01120), funded by the Italian Ministry of Education, Universities and Research, under the National Operational Program Area “Technologies for Living environments”.

The primary aim is to evaluate the acceptability of the SI-ROBOTICS system in a group of patients with Parkinson’s disease while performing a rehabilitation treatment based on Irish dancing, using Unified Theory of Acceptance and Use of Technology (UTAUT) scale.

The secondary aim is the analysis of the modification of some dimensions related to the general functional status, in terms of gait, balance, fear of falling, cardiorespiratory performance, motor symptoms related to PD, quality of life due to the SI-ROBOTICS intervention.

2. Materials and methods

In this section, the experiment and the architecture of the SI-ROBOTICS system are presented.

2.1. Definition of the user requirements in the SI-ROBOTICS project

The study population consisted of 9 patients with PD, recruited in the outpatient Departments at the Clinical Unit of Neurology and Physical Rehabilitation, IRCCS INRCA, in the Ancona hospital. Study participants met the following inclusion criteria: aged 65 and over in an early-stage Parkinson's disease (Hoen and Yahr scale of 1-2 stage [15]) with the ability to give consent. In addition, patients could have a Functional Ambulation Category [16] (FAC) $\geq$ 2, a Ranking scale [17] score $\leq$ 3, a Geriatric Depression Scale 4-items [18] $\leq$ 1, a Mini Mental State Examination [19] $\geq$ 24 and should be able to maintain an upright posture for 30 seconds. Moreover, a standard assessment was performed in all patients, including: clinical history, assessment of the the prognosis of Parkinson's disease with the Unified Parkinson's Disease Rating Scale - III (UPDRS – III) [20], measurement of functional state with the Barthel Index (BI) [21], Gait and Balance performance on Tinetti's Performance Oriented Mobility Assessment (POMA) [22], assessment of the function of the lower limb with the Short Physical Performance Battery (SPPB) [23] and the person's level of mobility through the Time Up and Go (TUG) [24], evaluate of a patient's residual functional capacity with the 6 Minute walking test (6MWT) [25], evaluation of Quality of Life with SF-12 health survey (SF-12) [26] and fear of falling with Falls Efficacy Scale – International (FES – I) [27], evaluation of acceptance of a technology through the Unified Theory of Acceptance and Use of Technology (UTAUT) [28].

After the recruitment stage, the enrolled patients were divided in two groups according their main goal: increasing the physical performance or reducing the risk of falls.

A 16-treatment session is conducted, divided into 2 training sessions per week, for 8 weeks. The rehabilitation sessions last 60 minutes; each session will involve 2 patients at time. Cardiac and respiratory activity monitoring is planned during dancing treatments in order to detect the heart rate and breathing frequency.

2.2. SI-ROBOTICS system architecture

The SI-ROBOTICS system is composed of multiple technological components, with the aim of facilitating a rehabilitation program based on Irish dance and encouraging the execution of dance steps. In addition, kinematic and performance parameters will be collected, which will be used by the physiotherapist to evaluate and plan subsequent sessions, and by the system to delineate the levels of difficulty of the exercise. The SI-ROBOTICS system consists of:

- **Robotic platform**: a social robot that allows the monitoring of patients during sessions, moving around patients safely and, if necessary, intervening in their support. The MoVeR1 robotic platform (Co-Robotics, Italy) is a two-axle autonomous vehicle with two front driving wheels and two rear omni-drive wheels, represents the main part of the whole platform. The platform is also equipped with: a microphone and a speaker to for vocal interaction with user; a tablet for displaying a web interface that supports the service; an Intel RealSense D435i RGB-D camera (Intel, USA), which measures movements and performs the remote plethysmography service by real-time measurement of electrocardiographic and respiratory signal; a SICK TIM781 laser 2D, able to detect obstacles and people in the environment. The software of the robot is based on Robot Operating System (ROS), which performs the function of the middleware, i.e. connection layer of all software components strictly related to the operation of the robot. Among the relevant modules built on ROS, there is the autonomous navigation module, in charge of performing motor control, avoiding obstacles, planning the best paths and so on. Furthermore, for the user interaction part, there are basic modules that deal with synthesizing text into dialogs. Figure 1 shows the robotic platform.

Figure 1: SI-ROBOTICS robotic platform

- **Let's Dance game**: a component that allows users to enjoy the game sessions (setting up of therapy sessions by the therapist, presentation of tasks to the player and execution by the latter, display of feedback on the sessions). The game is based on levels of increasing difficulty that can contain different types of tasks representing specific physical activities to be performed by the patient. During the execution of the game, the player is tasked with performing specific dance steps in sequence, which involve the lower and/or upper limbs and are presented in the form of individual tasks. The SI-ROBOTICS system will use a combination of steps to create a sequence to be performed, which is congruent with the chosen song, the level of difficulty and the therapeutic objective pursued.
- **Environmental and wearable sensors**: the Wearable Wellness System (WWS) sensorized shirt, produced by Smartex (http://www.smartex.it/it/prodotti/204-wws) allows data to be collected on the patient's main clinical parameters (e.g. heart rate and breathing frequency). The shirt is also equipped with a processor which filters the signals for reducing artifacts and noises. Heart rate and breathing frequency are strictly correlated with stress, allowing the therapist to know the patient's effort during the execution of tasks and the AI reasoner component (see below) to have an additional level of information with which to adapt the planning of steps.
- **AI reasoner**: this is the backend of the SI-ROBOTICS system, i.e. the "intelligent" component that allows the adaptation of the game sessions, based on the users' game performance and the data collected through the sensors. In this way it will be possible to dynamically customise the session according to the user's needs and abilities.
- **Artificial vision setting**: a commercial camera called Inter Real Sense (https://www.intel.it/content/www/it/it/architecture-and-technology/realsense-overview.html) will be installed in the experimental setting for the extraction of kinematic parameters, saved anonymously and locally on this computer. Also the robotic platform will be equipped with a RealSense camera and will be able to acquire kinematic parameters. To extract features of interest from the signals, proprietary skeleton tracking software of the Real Sense camera is used, together with specially developed algorithms for feature extraction. The extracted features are:
    a. step symmetry;
    b. symmetry between left and right foot;
    c. symmetry between left and right arm;
    d. flexion of the trunk; a warning is triggered when the person tilts the trunk forward exceeding the tolerance.
    e. the center of gravity; the system gives a warning when the projection of the center of mass exits the support base defined by the length and position of the feet

Figure 2 shows the experimental setting in a protected environment and the positioning of the technologies, the user and the physiotherapist, during the training sessions. The robot will move without entering the rehabilitation area, using the navigation algorithm based on literature algorithms for robots of this type.

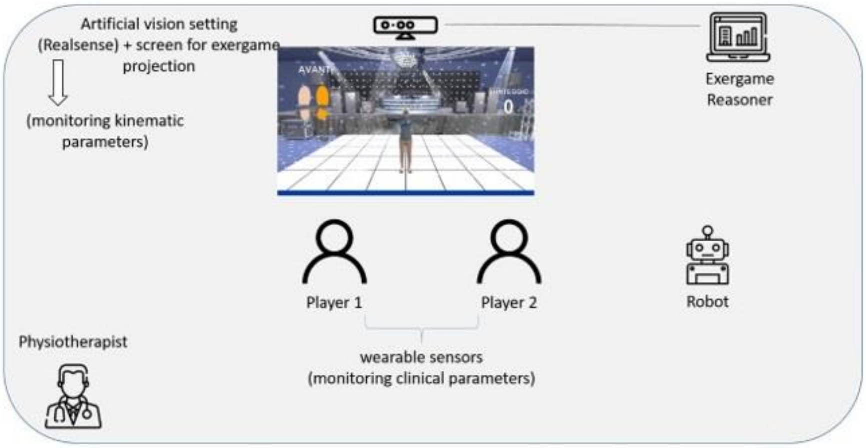

Figure 2: SI-ROBOTICS experimental setting

3. Results

We present a series of the nine patients (PD_01 – PD_09) involved in the study. Patients enrolled in the study were aged 75.4±5.3 years old, and consisted of 5 men and 4 women. Mean Hoen and Yahr scale was 1.8±0.3, indicative of a unilateral and axial involvement (Table 1). One participant (PD_08) dropped the experimentation because of familiar problems occurred between T0 and T1. For this reason, she has been taken into account only in Table 1, where demographic data are shown.

Table 1
Baseline demographic and clinical profile

	Total (n=9)	Male (n=5)	Female (n=4)
Age (mean±SD)	75.4±5.3	74.6±3.9	76.5±7.3
Marital status			
Married	7 (77.8%)	5 (100%)	2 (50%)
Single	1 (11.1%)	0	1 (25%)
Widowed	1 (11.1%)	0	1 (25%)
Educational level			
No education	0	0	0
Primary education	0	0	0
Secondary education	7 (77.8%)	4 (80%)	3 (75%)
University or more	2 (22.8%)	1 (20%)	1 (25%)
Hoen and Yahr score	1.8±0.3	2.0±0.0	1.7±0.5
Rankin scale score	1.0±0.0	1.0±0.0	1.0±0.0
GDS	3.4±0.7	3.2±0.8	3.7±0.5
FAC	5.0±0.0	5.0±0.0	5.0±0.0
MMSE	29.5±0.01	29.8±0.4	29.25±1.5

SD=Standard Deviation; GDS= Geriatric Depression Scale; FAC=Functional Ambulation Profile; MMSE=Mini-Mental Statement Examination

3.1. Usability and acceptability of the system

In Table 2 the UTAUT scales results are shown. All patients demonstrated a positive attitude towards the service, trusted the system, and enjoyed the experience, by perceiving the system easy to use. Most of the patients perceived the system as useful, and did not feel anxious during the use. They thought to easily adapt to the system, in fact they thought to not require any external aid. Patient PD_01, PD_04, and PD_05 felt quite anxious in using the system. Moreover, PD_04 did not find the platform very useful. However, the UTAUT scores lead to think that the usability of SI-Robotics system is satisfactory.

Table 2

Results of UTAUT scales. (Scale from 1 to 5 where 1=strongly disagree and 5=strongly agree)

PD_01	3.5	4.0	2.0	1.0	3.6	3.2	3.0	4.0
PD_02	1.5	4.7	4.5	5.0	3.8	3.6	5.0	5.0
PD_03	1.0	5.0	2.0	5.0	4.2	3.6	4.3	4.0
PD_04	4.0	4.0	1.0	3.0	4.0	2.8	1.3	3.0
PD_05	4.3	4.0	1.0	4.0	3.0	4.4	3.3	4.0
PD_06	1.3	3.7	1.0	3.7	4.0	4.0	4.7	4.0
PD_07	1.0	2.7	1.0	3.0	3.6	3.8	3.3	2.0
PD_09	1.3	4.3	1.0	2.3	3.4	3.0	3.0	4.0

ANX: Anxiety, ATT: Attitude, FC: Facilitating Conditions, PAD: Perceived Adaptability, PENJ: Perceived Enjoyment, PEOU: Perceived Ease of Use, PU: Perceived Usefulness

3.2. Mobility functional results

In this section the results about evolution of patients' mobility (6 Minute Walking Test, Short Physical Performance Battery, Tinetti's Performance Oriented Mobility Assessment, and Time Up and Go) are reported in Table 3 and 4 for group 1 and 2 respectively.

Table 3

Results for group 1

	PD_01	PD_02	PD_03	PD_04
Age	67	69	84	76
Gender	F	M	F	M
Hoen and Year scale	1	2	2	2
6MWT (T0) [m]	337	310	358	510
6MWT (T1) [m]	460	360	388	540
6MWT (T2) [m]	445	428	325	557
SPPB (T0)	9	8	8	9
SPPB (T1)	10	9	10	11
SPPB (T2)	10	10	7	11
POMA (T0)	27	23	23	27
POMA (T2)	28	26	24	28
TUG (T0) [s]	7.2	14.97	12.04	11.44
TUG (T2) [s]	9.05	10.2	9.37	7.56

6MWT=6 Minute Walking test; SPPB= Short Physical Performance Battery; POMA= Tinetti's Performance Oriented Mobility Assessment; TUG=Time Up and Go

Assessment and objective examination of patient PD_01 showed no major deficits, good balance, and low fall risk. In fact, her primary goal was to increase physical performance. The patient presented good compliance with treatment, she had no problems using the system, requiring little assistance. Physical performance, assessed by the 6MWT and SPPB, increased significantly. At the end of treatment, the greatest improvement was seen in the 6MWT, whereas the increase in SPPB was less noticeable.

PD_02 has been diagnosed with the Parkinson's disease 8 years earlier. Objective examination demonstrates poverty of general movements, bradykinesia, gait pattern with small crawling steps, and minimal rigidity. Tremors and freezing were not appreciated during evaluation and treatment. The primary goal for the patient was to improve gait pattern, reduce the risk of falling, and increase speed. During the sessions, excellent patient compliance was appreciated and the patient was always motivated to perform the treatment. The patient showed consistent improvement in the 6MWT and SPPB. The patient showed substantial improvements in the item where he was required to repeatedly get up and sit down from the chair.

Objective examination and evaluation demonstrated a good degree of function and a low risk of falling for PD_03. The primary goal for this patient was to increase physical performance. The patient in using the system had no problems and did not need any aids in use. Physical performance did not show the expected improvements as the patient experienced hip pain that significantly affected the 6MWT; the onset of pain was not attributable to the treatment performed with the system. In less demanding trials such as the TUG and SPPB showed improvement in both pre- and post-treatment assessments. Occasional indications were needed to use the system.

On objective examination, PD_04 showed amimic facies, monotone voice, and poverty of spontaneous movements. However, the gait pattern was well preserved. The patient showed difficulty in using the system as he was unfamiliar with the technology and help from the therapist was frequently needed. Evaluations demonstrated consistent improvement in the 6MWT and in the SPPB.

Table 4

Results for group 2

	PD_05	PD_06	PD_07	PD_09
Age	80	78	72	78
Gender	F	M	M	M
Hoen and Year scale	2	2	2	2
6MWT (T0) [m]	312	420	510	400
6MWT (T1) [m]	303	376	420	420
6MWT (T2) [m]	300	440	398	425
SPPB (T0)	8	11	5	9
SPPB (T1)	10	10	9	12
SPPB (T2)	10	12	11	12
POMA (T0)	22	25	19	27
POMA (T2)	24	27	28	28
TUG (T0) [s]	14.66	10.56	9.69	10.56
TUG (T2) [s]	9.56	6.80	8.76	6.80

6MWT=6 Minute Walking test; SPPB= Short Physical Performance Battery; POMA= Tinetti's Performance Oriented Mobility Assessment; TUG=Time Up and Go

About PD_05, objective examination shows only an unsteady gait and reduced balance in static and dynamic phases albeit with no history of falls in the past year. The objective examination and assessments showed reduced balance in both dynamic and static phase, assessed by the SPPB and the Timed up and go. The primary goal was to provide greater safety and reduce the risk, albeit minimal, of falling. The sessions were conducted as per protocol with adherence and participation by the patient. At the end of the treatment, a significant improvement in TUG was appreciated, as for the POMA scale. The patient also felt an improvement in her gait feeling more confident. The patient suffers from gonalgia due to a chronic degenerative disease, mild in degree, which certainly has an 'influence on her gait pattern on which the system had no effect.

Objective examination and evaluations revealed that PD_06 was suffering from bradykinesia, impaired gait pattern, amimic facies, and mild rigidity. However, the patient was autonomous in all his daily activities. The primary goal for the patient was to improve the gait pattern. The patient immediately showed good confidence with the system, which did not need any special help in using the system from the therapist. Comparing evaluations between before and after treatment, the patient noted an increase in confidence while walking, and the TUG improved considerably as shown in Table 3.

PD_07 presented a slow gait, reduced in height and length, with limited trunk rotation, and reduced pendular synkinesias of the upper limbs during walking. In addition, the patient had severe flatness of the feet that affected gait and his sense of security. Poor foot support affected the outcomes that predicted walking (6MWT and TUG) in which improvements were not appreciated. Improvements were more appreciated in the POMA test which also assesses balance in the static phase. The patient frequently uses computer devices and therefore did not need directions while using the system.

The objective examination highlighted bradykinesia, poverty of spontaneous movements, mild camptocormia, and altered gait pattern of PD_09. The patient was autonomous in all his daily autonomy. The patient had some difficulty while using the system. The patient's primary goal was to improve gait pattern and reduce the risk of falling. The patient showed considerable improvement in all assessments. The most substantial improvement was in the TUG, whereas the 6MWT and POMA presented improvements but to a lesser extent.

4. Discussions

Given the preliminary results, SI-ROBOTICS is a usable and efficient system for people affected by Parkinson disease. The eight participants who have experienced the system for 16 sessions did not encounter particular problems in using the technology. This aspect, combined with the attractiveness and engagement of a robotic system [29], might affect positively also the clinical impact. In particular, combining the customization and adaptability of the proposed rehabilitation technology [30] with robots to encourage the participants during the training with Irish dancing [31-35], might have strongly motivated the PD patients in participating to the rehabilitation program, by promoting satisfactory pattern [36] and distracting by fatigue [37]. In fact, most of patients improved in their goal. For these reasons, SI-ROBOTICS can be considered effective in treating patients with Parkinson disease, even though further studies with larger population are needed to prove the impact that this technological solution can bring.

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