Acceptability and clinical usefulness of a telemonitoring and telerehabilitation system in people with Parkinson's Disease in different disease stages: preliminary findings from the RAPIDO study.

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Abstract

Telemonitoring and telerehabilitation techniques are significant approaches for people with Parkinson's disease (PD) to improve their clinical health status. In this work, we present a system to monitor people with PD during their physical exercise sessions. Wearable devices are used to collect 24-hour health parameters, that are successively stored on a remote server and then analyzed. A clinical and technical analysis has been conducted on this data; the second one exploits techniques such as the Tukey test, PCA technique, and the K-means clustering algorithm.

The main goal is to identify changes in patients' health status over 3 months (monitoring period) and assess the acceptability of the system.

Keywords

Data Analysis, Healthcare, Telerehabilitation, Telemonitoring, Parkinson's Disease, Smartwatch.

1. Introduction

Parkinson's disease (PD) is a neurodegenerative disorder that impacts a significant and constantly growing number of people worldwide ([1]; approximately 1-2% of the population over 65 years old and about 3% of individuals over 80 years old). The cardinal motor symptoms, such as bradykinesia, muscular rigidity, resting tremor [2], postural and gait impairments, and difficulties in speech and swallowing, are the most recognizable manifestations of PD. These symptoms are considered clinical markers for assessing the progression and severity of the disease. However, PD is also characterized by several non-motor symptoms (e.g., sleep disorders, mood disorders, depression, alexithymia, etc.) with a strong impact on patients' quality of life. Hence, the clinical evaluation of PD focuses on studying its motor and non-motor manifestations. This evaluation is typically carried out using standardized scales and questionnaires. Clinicians assess symptoms through medical interviews and clinical examination, while patients provide information about their habits and perceptions of the disease. However, most assessment measures lack sensitivity to change, especially in the early stage of PD, and may not be fully suitable for studying the disease's progression in such phases [3].

As a result, there is growing interest within the scientific community in the use of sophisticated technologies for the clinical monitoring of people with PD [4]. Wearable devices have emerged as

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a promising alternative to current diagnostic tools, offering an efficient means of detecting PD in its early stages [5]. For therapeutic purposes, pharmacological and non-pharmacological approaches are available, to alleviate symptoms in PD patients [6]. These therapies encompass drugs, such as Levodopa-based preparations and physical activity. It has been demonstrated that rehabilitation through physical activity can attenuate motor symptoms, reduce disability progression, and improve the overall quality of life for PD patients [6,7]. Therefore, incorporating a physical activity plan into the treatment regimen is crucial for managing PD [8]. Furthermore, telerehabilitation and telemonitoring techniques have emerged as innovative and effective approaches for managing patients with PD [9,10], benefiting patients, healthcare providers, and the healthcare system.

According to the mentioned guidelines, our work proposes a telerehabilitation and telemonitoring system designed to reduce the costs that a standard rehabilitation therapy in presence would have for the healthcare system and caregivers. The system is developed within the project RAPIDO (teleRehabilitation for pAtient with ParkInson's Disease at any mOment), started in 2021 from the collaboration between Politecnica delle Marche University and Verona University and supported by Fondazione Cariverona (Grant Agreement Call R&D 2020 Prot. 2020.0069 - ID 11656). The primary objective of this paper is to analyze the feasibility and acceptability of the system as mentioned above, as well as to provide a methodological solution to analyze data collected from wearable sensors that can detect changes in patients' health status.

The proposed method first identifies the most significant variables, showing any changes throughout the telerehabilitation period, and then presents an unsupervised clustering technique to find an interesting structure of patients' health data and if this structure has any consistent relation with the advancement of the telerehabilitation program.

2. Material and methods

2.1 System Architecture

As described in [11], individuals with PD use a smartwatch (Garmin Vivosmart 4) to track their health condition and a tablet (Samsung A7) to watch videos related to the exercises following the rehabilitation program that clinicians prescribed to them. The information gathered from the smartwatch is transmitted to a remote server and later examined to observe the users' health condition progression. The structure of the system is illustrated in Fig. 1.

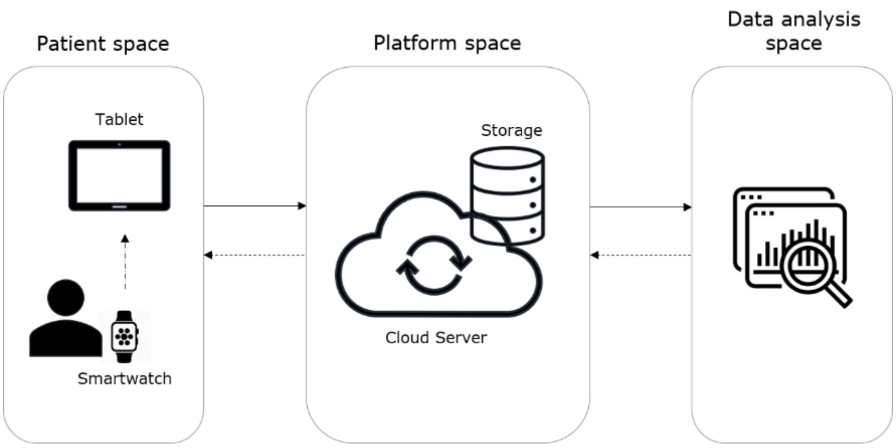

Figure 1: Architecture of the used telemonitoring system

2.2 Participants and Clinical Protocol

We enrolled people of either sex with a diagnosis of Parkinson's disease who exhibited the following eligibility criteria: age over 18 years; provision of written informed consent, ability to perform the physical exercises and interact with the system, presence of family support, Hoehn and Yahr (HY) disease stage ≤ 4 (still able to walk also with physical help in at least few minutes of the day, absence of moderate to severe depression, dementia or other neuropsychiatric disorders.

Participants' enrollment is still in progress. This work presents preliminary data from 31 subjects who completed the 3-month follow-up.

2.2.1 Procedures

Over 12-week, participants should follow a telerehabilitation program, accessing the web platform to perform training sessions proposed by clinicians three times a week. Each training session comprises several exercises which need about 45 minutes to be completed. The clinicians designed 4 different rehabilitation protocols, each containing 36 training sessions. They matched each participant with the most suitable rehabilitation protocol on enrollment, according to the disease stage and health condition. The attending physicians provided the clinical and functional assessment of patients at enrolment and 12 weeks later, applying a set of quantitative measures routinely used to monitor the burden of motor symptoms (Unified Parkinson's Disease Rating scale-UPDRS), non-motor symptoms (Non-Motor Symptom Scale -NMSS), and health-related quality of life (PDQ-8). Changes in disease-specific clinical measures, as the UPDRS II and III scores and the NMSS score may signal PD progression or, conversely, indicate treatment efficacy. Changes in PDQ-8, a patient-reported outcome, are used as proxies of perceived well-being.

Finally, the System Usability Scale (SUS) was administered at the end of the 3-month period to assess the perception of ease of use of the telerehabilitation and telemonitoring system.

Table 1 synthesizes the content and scoring system of the quantitative clinical measures applied.

2.3 Data Collection

The experimental protocol requires each participant to wear a smartwatch (Garmin Vivosmart 4) throughout the day. This enables data collection regarding daily motor and sleep activities for subsequent analysis. The smartwatch transfers the data in anonymous format to the tablet using Bluetooth, which then forwards the gathered data to a remote server via the Garmin Connect App. Once it arrives on the server, the data is saved as summary logs (in JSON format) and can be retrieved for future analysis. Data is not pre-processed but used as provided by Garmin. An example of the provided features can be found on table 2, while the complete list of all the collected variables can be found in Garmin documentation and [12].

Only authorized personnel can access and manage the information and data stored in the remote server. All patients' data uploaded on the platform have been anonymized.

The features recorded by the smartwatch are used as indices of the amount of physical activity performed by the patients during the study period and proxies of their general health status. None of the parameters collected by the smartwatch is an index of disease.

2.4 Data Analysis

The primary objective of the data analysis was to see if the telerehabilitation system influenced any health habits or physiological changes in patients over the 3 months of exercise. Daily summaries from the smartwatches worn by the participants were used for this analysis, extracting 35 features every day, the entire analysis was performed separately for each patient.

Table 1. Main features of the clinical outcome measures applied in the RAPIDO study

Outcome measure	Acronym	Score Range	Meaning
Hoehn & Yahr	HY	1-5	Disease-related disability staging; score $\geq$ 3 = severe disability
Body Mass Index	BMI		kg/m2 (Normal range = 18.5 to 24.9)
Comorbidity Illness Rating scale	CIRS	1-4	Comorbidity index: 1=no comorbidity.
Montreal Cognitive Assessment	MoCA		Validated screening tool for Cognitive functions: >26/30 = normal function; 18-22 = mild cognitive impairment; <22 cognitive impairment.
UPDRS Activities of Daily Living	UPDRS II-ADL	0-52	UPDRS II part assessing disability.
UPDRS motor part	UPDRS III	0-108	UPDRS III part assessing motor symptoms
Non-Motor Symptom scale	NMSS	0-360	international validated measure of non-motor features: the higher the score the greater the severity of symptoms
Parkinson's Disease Quality of life-8	PDQ	0-32	8-item rating scale assessing PD-related quality of life: the higher the score the worse quality of life
System Usability Scale	SUS	0-100	10-item questionnaire designed to evaluate a wide variety of products and services, including hardware, software, mobile devices, websites and applications.

Figure 2 outlines the process for analyzing this data: Firstly, features were grouped by weeks, and the Tukey Honestly Significant Difference (HSD) test was performed on each feature for pairwise comparison between different weeks.

Only those features showing significant changes between weeks (with a p-value less than 0.05) were further analyzed. Then, Principal Component Analysis (PCA) was performed on these features, which helped simplify complex data into main components for easier interpretation. The number of PC to use for subsequent analysis was chosen to reach at least 90% of the explained variance. Due to his/her clinical history and medical condition, every subject has a different number of PC.

The new PCA data was used as input for an unsupervised learning method called K-means clustering. This technique was chosen since the collected data are not labeled in advance, and clinicians did not define a list of possible classes that could be assigned to each observation in the dataset. They were only interested in searching for any significant changes in the patient's condition. K=3 was chosen to separate data into different clusters. An interesting analysis was to compare the cluster identity of each point with the belonging of the same point to the first, second, or third month of observation (it will be called month identity). The match between cluster identity and month identity can be measured using a confusion matrix, where the month identities are regarded as "true values", and cluster identities as "predicted values". Accuracy is then calculated from the confusion matrix.

Table 2
The main features provided by Garmin Server in the daily summary

Property	Type	Description
summaryId	string	Unique identifier for the summary
calendarDate	string	The calendar date this summary would be displayed on in Garmin Connect. The date format is ‘yyyy-mm-dd’
startTimeInSeconds	integer	Start time of the activity in seconds since January 1, 1970, 00:00:00 UTC (Unix timestamp).
startTimeOffsetInSeconds	integer	Offset in seconds to add to startTimeInSeconds to derive the “local” time of the device that captured the data.
activityType	string	This field is included in daily summaries for backwards compatibility purposes. It can be ignored and will always default to WALKING.
durationInSeconds	integer	Length of the monitoring period in seconds. 86400 once a full day is complete, but less if a user syncs mid-day.
steps	integer	Count of steps recorded during the monitoring period.
distanceInMeters	float	Distance traveled in meters.
activeTimeInSeconds	integer	Portion of the monitoring period (in seconds) in which the device wearer was considered Active. This relies on heuristics internal to each device.
activeKilocaries	integer	Active kilocalories (dietary calories) burned during the monitoring period. This includes only the calories burned by the activity and not calories burned as part of the basal metabolic rate (BMR).
bmrKilocalories	integer	BMR Kilocalories burned by existing Basal Metabolic Rate (calculated based on user height/weight/age/other demographic data).
consumedCalories	integer	The number of calories that have been consumed by the user through food for that day (value subtracted from calorie goal). This value is received from MyFitnessPal and is not entered within Connect.
moderateIntensityDurationInSeconds	integer	Cumulative duration of activities of moderate intensity. Moderate intensity is defined as activity with MET value range 3-6.

The main idea is that a high match between clusters and months (high value of accuracy) indicates that health data across months are separated and distinct, similarly to clusters, possibly suggesting that the participant's health changed over the 3 months. From a clinical standpoint, if data from the same month falls in the same cluster, it means that there is a steady health trend.

Otherwise, scattered data suggests fluctuating health without clear progression. Based on the values of accuracy obtained for each patient and on the clinical assessments after the 3 months telerehabilitation period, that established if clinical condition is stable, worsen or improved, it was investigated if a threshold can be set on the accuracy in order to classify a certain participant as stable or not stable (worsen or improved).

Lastly, the system acceptability was evaluated through the adherence of participants to the rehabilitation protocol and smartwatch usage. Specifically, adherence was measured as the percentage of completed training sessions over the total number of training sessions, while smartwatch usage was measured as the percentage of correctly monitored days over the 3 months period. A day was considered correctly monitored if the smartwatch sent the daily report to the server (if the user does not wear the smartwatch, no report is generated). The study was performed according to the Declaration of Helsinki and approved by the Local Institutional Committee on April 21st, 2022 (protocol number: CERM-2022-27). All participants signed informed consent forms before participating in the study.

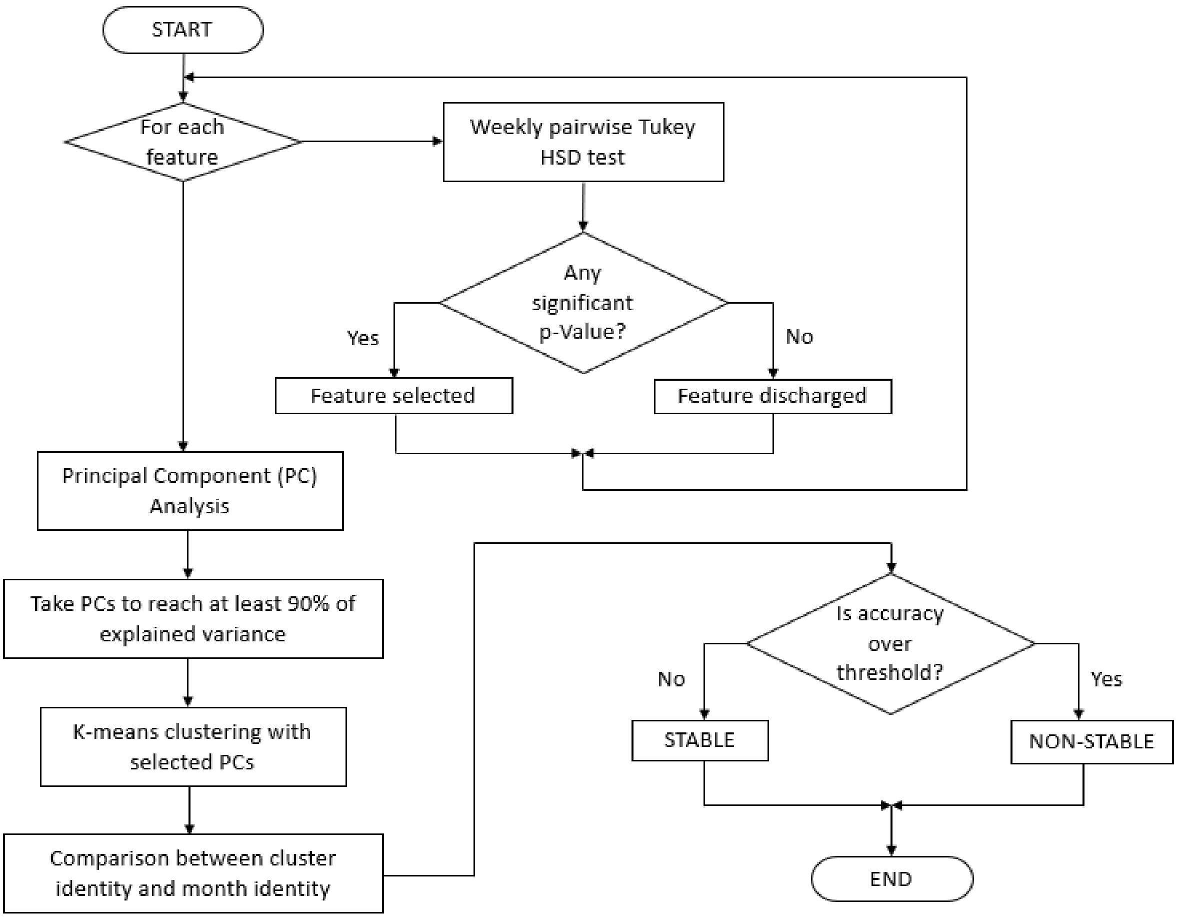

Figure 2: Flowchart of the data analysis process

3. Results

The clinical and technical results are presented separately in the following subsections.

3.1 Clinical Results

Patients' demographic and clinical features at enrolment are detailed in Table 3. Data is presented as mean and standard deviation (SD) for the total sample and for subgroups HY stage

1-2 and HY stage 3-4. Inter-group comparisons are also provided with respective p-values. Out of the 31 enrolled subjects, 22 were male. Twenty-three patients were in the early, milder disease stage, i.e., in the Hoehn & Yahr-HY stages 1-2, whereas 8 in the advanced disease stage (HY stage 3-4). As expected, the subgroup in the advanced disease stage showed a longer disease duration, higher dependence on ADL (UPDRS-II ADL score), and poorer quality of life (higher PDQ-8 score), than people with a mild condition (HY 1-2).

At 3 months, the clinical and functional assessment did not reveal any statistically significant change in any outcome measure. No subject complained of side effects or adverse events correlated to the training experience.

The compliance with the study protocol was quite high, with 68% of the total sample completing more than 70% of the assigned sessions. This value ranged from 74% in subjects in HY stages 1-2 to 50% in those with HY stages 3-4.

The perception of system usability at the end of the study period was overall high with all people, both in the early and advanced phase, reporting SUS scores higher than 70.

Table 3

Demographic and clinical features of the enrolled sample. Data refer to the total sample of 31 subjects, and to the subgroups of people in different disease stages. Legenda: HY= Hoehn & Yahr; BMI= Body Mass Index; CIRS= Comorbidity Illness Rating scale; MoCA= Montreal Cognitive Assessment; UPDRS= Unified Parkinson's Disease Rating scale; ADL= activities of Daily Living; NMSS= Non-Motor Symptom scale; PDQ= Parkinson's Disease Quality of life; SD= Standard Deviation

Parameter	**TOTAL (N. 31) [mean (SD)]**	**HY stage 1-2 (n. 23) [mean (SD)]**	**HY stage 3-4 (N.9) [mean (SD)]**	**Inter-group comparison p-value**
Age(years)	68,4 (8,7)	66,6 (8,3)	73,5 (8,5)	n.s.
Education(years)	13,1 (4,1)			
BMI	25,7 (4,0)	25,8 (4,3)	25,3 (2,9)	n.s.
Disease duration(years)	7,1 (4,3)	6,0 (3,0)	10,2 (5,9)	**<0,01**
CIRS score	1,1 (0,7)	1,0 (0,5)	1,5 (1,1)	n.s.
MoCA score	25,6 (3,1)	26,3 (2,7)	23,9 (3,9)	n.s.
UPDRS II-ADL	9,7 (5,6)	7,7, (3,4)	15,5, (3,8)	**<0,01**
UPDRS III	19,9 (8,3)	18,0 (11,0)	25,1 (15,1)	n.s.
NMSS	47,8 (34,2)	43,2 (33,1)	62,7 (36,1)	n.s.
PDQ-8	6,9 (4,7).	5,4 (3,7)	11,4 (4,6)	**<0,001**
SUS	74,0 (13,5)	70,9 (6,6)	79,0 (20,5)	n.s.

Based on data recorded through the smartwatch, the analysis of motor behavior exhibited daily over the 3-month observation period, produced different results in the two subgroups with different disease severity.

People in HY stages 1-2 showed a trend towards increasing the number of steps (Figures 3-4) and the distance (meters) covered each day (Figures 5-6). The increase started after the first week to reach a maximum in the second week and remained overall stable up to the 10th week to decrease afterward slightly. Energy expenditure showed a similar trend (Figures 7-8). People in HY stages 3-4 did not show any recognizable trend. However, this subgroup comprised only 8 people who provided very different performances, so this inhomogeneity likely prevented the definition of standard behavior.

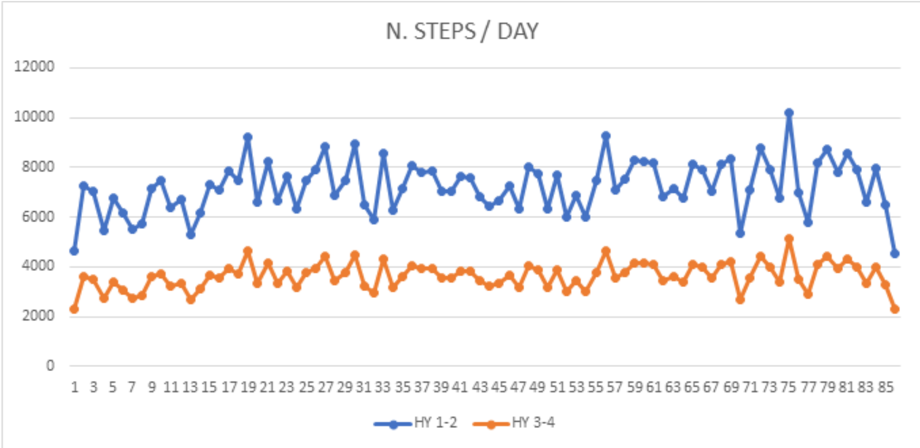

Figure 3: Number of steps/day (average values recorded daily in the subgroups of people with mild (HY stage 1-2) or advanced disease (HY stage 3-4)

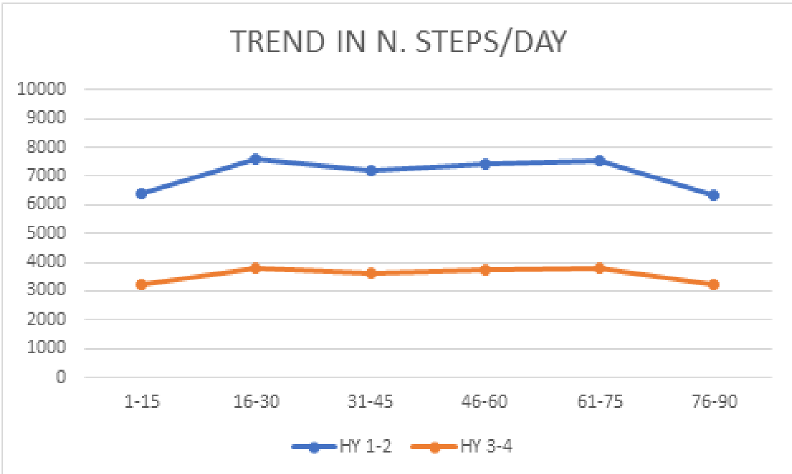

Figure 4: Trend in the number of steps/day (values are averaged over 2-week periods in the subgroups of people with mild (HY stage 1-2) or advanced disease (HY stage 3-4)

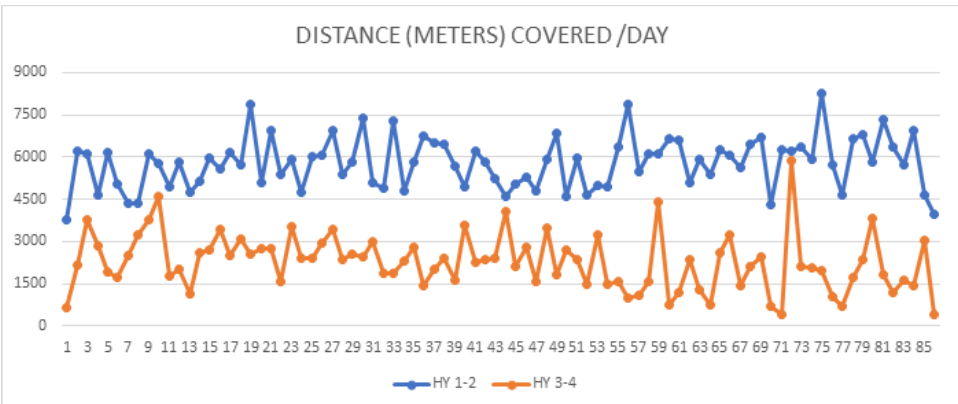

Figure 5: Distance (meters) covered /day (average values recorded daily in the subgroups of people with mild (HY stage 1-2) or advanced disease (HY stage 3-4)

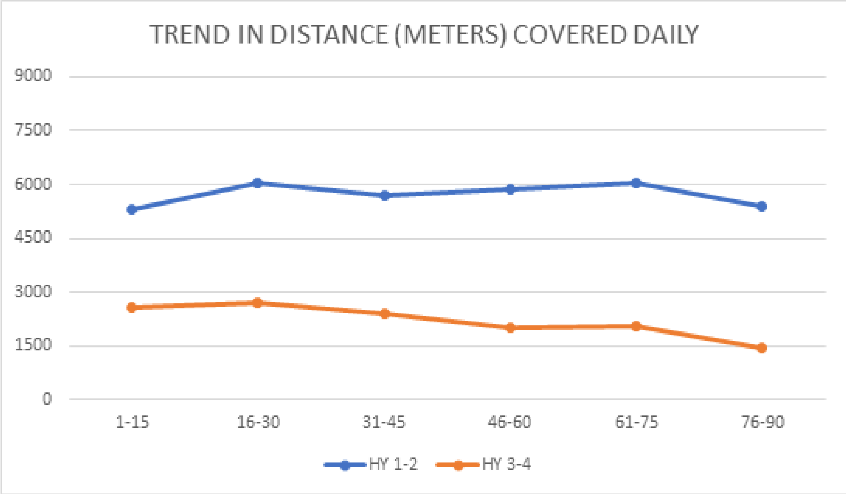

Figure 6: Trend in distance (meters) covered daily (values are averaged over 2-week periods in the subgroups of people with mild (HY stage 1-2) or advanced disease (HY stage 3-4)

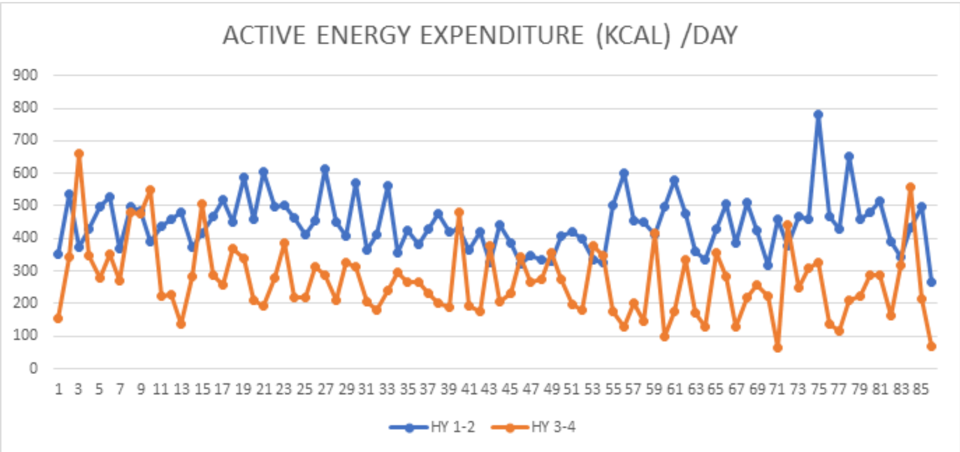

Figure 7: Active energy expenditure (kcal) /day (average values recorded daily in the subgroups of people with mild (HY stage 1-2) or advanced disease (HY stage 3-4)

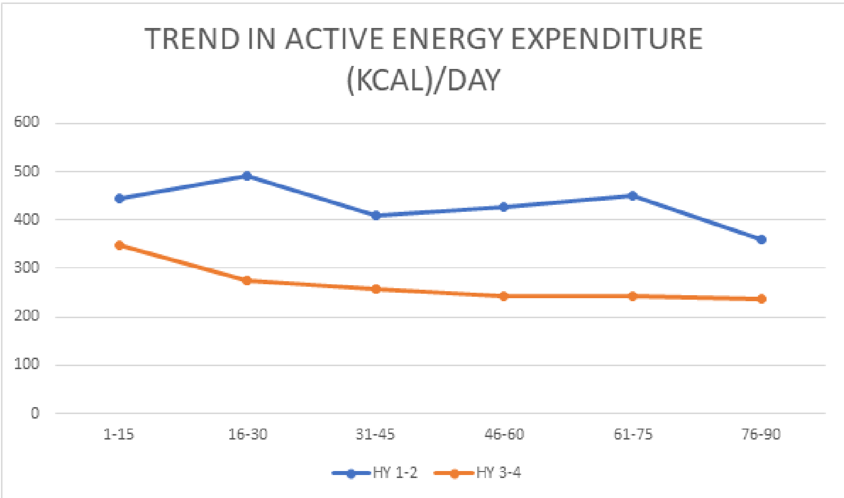

Figure 8: Trend in active energy expenditure (kcal)/day (values are averaged over 2-week periods in the subgroups of people with mild (HY stage 1-2) or advanced disease (HY stage 3-4)

3.2 Technical Results

3.2.1. Health Status Monitoring

Among the enrolled participants, 60% were considered clinically stable after the telerehabilitation period, while the other 40% manifested changes (improved or worsen). Mean values of accuracy measure between cluster and month identities were 47% and 65% for the stable and not stable conditions respectively. By setting a threshold of 60% on these accuracy values, the capability of the proposed analysis to classify a patient as stable and not stable can be measured through accuracy, precision, recall, and F1 score, as shown in Table 4.

Table 4
Confusion matrix of the clustering analysis

Class	Precision	Recall	F1 Score
NON-STABLE	83,33%	71,43%	76,92%
STABLE	85,71%	92,31%	88,89%
change detection accuracy		**85%**	

3.2.2. System Acceptability

Results reported in Table 5 show how adherence percentage differs between participants in the early disease stages (H&Y stage 1-2) and in the advanced disease stage (H&Y stage 3-4). As shown, PD patients belonging to the first category participated more actively to the telerehabilitation program.

Otherwise, the percentage of correct smartwatch wearing, and usage is almost the same.

Table 5
Adherence percentage to the rehabilitation program and smartwatch usage

	Adherence	Smartwatch usage
H&Y (1-2)	87%	84,15%
H&Y (3-4)	50,75%	85%

4. Discussion

The main aim of the current research is to analyze the acceptability of a telerehabilitation program, as well as to explore potential related changes in participants' health status over the 3-month intervention. Regarding the system's acceptability, we obtained encouraging results. Indeed, all participants complied with the study protocol, accepting to wear the monitoring device continuously during the day. As shown in Table 5, smartwatch usage percentage is near 85% for both patients with PD in the early stages (H&Y stage 1-2) and for patients in the more advanced stages (H&Y stage 3-4), demonstrating that most of the participants showed no difficulties in accepting the proposed system.

Looking at the intervention adherence, we found that PD patients in the early stages showed higher involvement and commitment than patients in the more advanced stages (Table 5 displays the percentage results obtained for participant adherence). Our results are in line with the literature [9], where feasibility projects related to telerehabilitation in PD patients with H&Y stage <3 [13] or <2 [14,15] showed acceptable adherence to the telerehabilitation program.

This evidence pushed us to consider the current program rich in potential benefits for people who are not called to fight against the advanced symptoms of the disease.

The intervention compliance was higher than 70% in almost two out of three patients, that is the expected value. The percentage was higher if considering people in the early stages of the disease. Considering motor outcome, our results highlighted that the number of steps increased in patients in the early stages of the disease but not in patients with H&Y stage 3-4.

Both adherence and compliance's evidence underlined the system is feasible and acceptable by patients with PD in the H&Y stage 1-2, suggesting that the current program might be further tested on this population, and further enhancements might be required for patients in the advanced stages. The current telerehabilitation program might be implemented in rural and remote geographical areas [15], and it should be promoted also among patients with mid-low socio-economic status [16].

Regarding the technical analysis, we propose a technique to identify possible changes in the health status based on PCA and K-means clustering.

Values reported in Table 4 show that the proposed method may be used to classify a patient as clinically stable or not.

40% percent of patients changed their health status after the telerehabilitation period and the average accuracy between clusters and month identities was 65%. This possibly indicates that data points are displaced in different clusters on the PC space during 3 months.

The remaining 60% percent of patients presented a clinically stable condition, reporting a mean accuracy of 47% between clusters and month identities. In this case, the more casual displacement of data points across months may be interpreted as the absence of significant change.

According to the presented discussion, a low accuracy may suggest a clinically stable condition, while a higher accuracy indicates a possible change in the patient' health status. From the collected data, a threshold of 60% proved to be suitable to quantitatively define "low" and "high" accuracy and hence detect a change in health status, yielding a quite high precision for both stable and not stable conditions (> 83%) and an 85% accuracy (Table 4).

The study was not designed to detect the impact of the telerehabilitation device on disease progression, as a 3-month period is too short to capture significant changes in the neurodegeneration process. That very period, however, is enough to detect behavioral changes, thus allowing us to reply to the question whether or not getting feedback on own daily physical activity and being involved in a structured telerehabilitation protocol impacts patients' behavior, by urging them to increase their daily physical activity. Preliminary results presented in this paper are encouraging.

5. Conclusions

This work presented the preliminary results of the feasibility and acceptability of a telerehabilitation program system for PD patients equipped with a telemonitoring device, used to measure autonomic functions and motor behavior to detect changes in the subjects' health status. We found encouraging results in PD patients in the early stage of the disease in terms of system acceptability and technical accuracy. Further enhancements are recommended for PD patients in the advanced stages who showed lower results in the intervention's compliance. Despite these promising findings, they may be conditioned by the limited sample size and need to be validated on a larger sample.

Furthermore, while the current analysis provides a quantitative assessment, it does not specify the direction of changes, be it negative or positive. The next step for future research would be to find a method that differentiates between patients who experience changes due to worsening versus those who show improvements. Hopefully, once our data collection is closed, our results might shed light on the overall usefulness of the system for people with PD at any stage.

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