SYSTEMATIC REVIEW

Received: 30 APRIL 2024 | Accepted: 15 MAY 2024 | **DOI:** https://doi.org/10.57849/ulisboa.fm.jscml.0000008.2024

JORNAL DA SOCIEDADE DAS CIÊNCIAS MÉDICAS DE LISBOA

Clinical dashboards for Parkinson's Disease monitoring: a systematic review

Filipa Ferreira-Brito [1,2*], **Diogo Branco** [1*], **Margarida Móteiro** [1], **Joaquim J. Ferreira** [3,4,5], **Tiago Guerreiro** [1]

[1] LASIGE, Faculdade de Ciências, Universidade de Lisboa, Portugal

[2] Instituto de Saúde Ambiental (ISAMB), Faculdade de Medicina, Universidade de Lisboa, Portugal

[3] Laboratory of Clinical Pharmacology and Therapeutics, Faculdade de Medicina, Universidade de Lisboa, Portugal

[4] Instituto de Medicina Molecular João Lobo Antunes, Faculdade de Medicina, Universidade de Lisboa, Portugal

[5] CNS - Campus Neurológico, Torres Vedras, Portugal

* *Both authors contributed equally to this manuscript*

Author contributions: *Conceptualization: FFB, DB, MM, TG and JF; Data Curation: FFB, DB and MM; Formal Analysis: FFB, DB and MM; Funding Acquisition: TG; Investigation: FFB, DB and MM; Methodology: FFB, DB, MM, TG and JF; Project Administration: FFB, DB, MM, TG and JF, Validation: FFB and DB; Visualization: FFB and DB; Writing – Original Draft Preparation: FFB and DB; Writing – Review & Editing: FFB, DB, MM, TG and JF.*

✉ **Corresponding author:**
Filipa Ferreira-Brito
LASIGE, Faculdade de Ciências, Universidade de Lisboa, Portugal
Campo Grande 1749 - 016 Lisboa, Portugal
Email: frbrito@fc.ul.pt

ABSTRACT: **Background:** Dashboards have been used in clinical settings to monitor Parkinson's disease (PD), serving as a means to visually represent collected data. However, there's a need to deepen understanding regarding the relationship between the types of data collected and the appropriate visualisation formats in clinical dashboards. Furthermore, the existing dashboards lack tailoring to the specific needs of both patients and healthcare professionals, and their clinical utility remains largely unexplored. **Methods:** We conducted a systematic review of the literature according to PRISMA guidelines based on the research protocol published at PROSPERO [CRD42021256047]. PubMed/MEDLINE, ACM and IEEE databases were searched in March 2024 for studies focused on developing and designing clinical dashboards for PD monitoring. **Results:** A total of 47 articles were included in the review. Sensors directly attached to the participant's body or embedded in various devices serve as the primary data collection tools. Among the included studies, most (39 out of 47) centred on monitoring motor symptoms such as tremors, bradykinesia, and dyskinesia, while only a small portion of the studies (8 out of 47) focused on other health-related outcomes. Notably, only a small fraction of studies (14 out of 47) involved end-users at some stage of system development, with only eight studies (8 out of 47) employing co-design or participatory design methodologies to develop dashboards with end-users collaboratively. **Conclusions:** This review underscores the prevalent use of sensors for gathering data on monitoring motor symptoms of Parkinson's Disease. Furthermore, our study also highlights a significant gap in end-user involvement in dashboard design, which impedes the advancement of knowledge regarding the optimal visual representation of clinical data.

KEY WORDS: Parkinson's Disease, Clinical dashboards, Data visualization, Disease monitoring

INTRODUCTION

Dashboards are visual means of representing and aggregating information (1). They enable the consolidation of data extracted from various sources (e.g., electronic devices) and facilitate user data navigation. There are various ways to display specific data, including tabular, textual, or graphical representations (1). Despite the existence of best practices for optimal information visualisation, it may be necessary to adapt the data presentation format depending on the user's needs (2).

Technology rapid advancements have introduced a multitude of devices into our lives, ranging from smartwatches to smartphones, each contributing to the generation of immense volumes of data (3). Dashboards serve as invaluable tools in organising this wealth of information. By aggregating and visually presenting data, dashboards facilitate comprehension and decision-making processes (4). Furthermore, they enable real-time monitoring and analysis, empowering users to respond promptly to changing circumstances.

In clinical practice, where a vast amount of information needs to be collected, whether through test batteries, questionnaires, or digital devices, dashboards can play a crucial role in facilitating consolidated access to this information (5). In healthcare, collecting and managing diverse datasets is paramount for effectively diagnosing, treating, and monitoring patients. Dashboards offer a centralised platform where healthcare professionals can efficiently access and analyse patient data, thereby streamlining decision-making processes and enhancing the quality of care. By aggregating data from various sources, including electronic health records, medical devices, and patient-reported outcomes, dashboards provide a comprehensive overview of patient health status and treatment progress (6).

Data collected from digital devices, complemented by appropriate visual representations such as dashboards, can prove highly beneficial for chronic diseases requiring continuous patient monitoring and management (3,7). This is particularly pertinent in the case of Parkinson's disease (PD), where not only is ongoing care necessary, but symptoms also fluctuate considerably over time and even throughout the day. Consequently, having access to consolidated information can significantly aid clinical practice.

Parkinson's Disease presents a unique set of challenges due to its progressive nature and the variability of symptoms experienced by patients. By leveraging data collected from wearable devices, smartphone applications, and other digital health tools, clinicians can gain valuable insights into the patient's condition beyond the confines of traditional clinical encounters (3,8). These insights enable personalised care planning, medication regimen optimisation, and early disease progression or complications detection. Moreover, the visualisation of longitudinal data trends through dashboards facilitates comprehensive assessment and promotes shared decision-making between patients and healthcare providers (4). Thus, the integration of digital health data with intuitive visualisations holds promise for improving the management and outcomes of PD and other chronic conditions requiring continuous monitoring and personalised care.

Several examples of utilising dashboards to enhance healthcare delivery and decision-making processes already exist (9,10). However, despite their promise, dashboards in clinical practice have yet to become a widespread reality. One of the reasons for this, is the lack of adaptation to the needs of healthcare professionals (11) and to evaluate their utility in clinical practice (12).

To the best of our knowledge, our work takes the initial step towards addressing the identified limitations by analysing the available literature on developing and designing clinical dashboards to monitor PD patients. For this purpose, we conducted a systematic review of the literature on clinical dashboards for PD monitoring. Through our efforts, we aim to contribute to the advancement of clinical dashboard design and progressively promote their integration into routine PD care, ultimately improving patient outcomes and enhancing the efficiency of healthcare delivery.

MATERIAL AND METHODS

This systematic review of the literature was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA 2020) (13) (S1 Table. PRISMA 2020 checklist), and it was based on a previous research protocol published at PROSPERO [CRD42021256047] (S1 File. PROSPERO Protocol)

Types of studies

To be included, studies had to present original data on developing clinical data visualisation dashboards intended for monitoring patients with PD. Articles considered for inclusion had to be published in English in peer-reviewed platforms such as journals and conferences. The search was not restricted by year of publication to avoid excluding potentially relevant articles.

Articles focused solely on technologies that do not aim to provide longitudinal evaluation of PD symptoms or those primarily concerned with PD diagnosis or screening were excluded. Additionally, reviews, study protocols, and grey literature, including case studies, books, book chapters, reports, thesis, editorials, and letters to the editor, were also excluded.

Electronic databases and search strategy

Electronic database searches on PubMed/MEDLINE, IEEE and ACM databases were conducted on the 26th of March 2024 using the following search string:

("Parkinson") AND *("monitoring"* OR *"assessment")* AND *("Report*"* OR *"dashboard"* OR *"data")* AND *("sensor*"* OR *"technolog*"* OR *"system*"* OR *"device*")*

For more information on database searches and search strings, see S2. Table Electronic databases and search strategies.

DATA EXTRACTION

The search results from the electronic databases were imported into Rayyan – Intelligent Systematic Review (14). Duplicates were automatically identified using Rayyan's built-in tool and manually excluded. Using the Rayyan platform, the remaining entries were independently screened by at least two reviewers (FFB, DB, MM) for title and abstract eligibility. Full-text evaluation and data extraction were performed using a spreadsheet. Any disagreements were resolved through reviewers' discussion or solved by a third party (TG or JJ).

Before the data collection process, we established consensus on concepts to ensure harmonisation among all team members during the data extraction process. According to our glossary:

- Technology to monitor health refers to objective measurement instruments to support clinical decision-making, including wearable sensors, sensors, electronic patient-reported outcomes (ePROs), robots, video cameras, and tablets/smartphones.
- Longitudinal monitoring refers to collecting evidence and evaluating a patient's condition over time, either through observation or objective quantification.

For data extraction, the following categories were included:

- Bibliographic information: title and study reference
- Study design: aim and context of the study, health-related outcomes, and technology employed
- Visual representation of clinical data: end-user involvement in dashboard design, methods, level of data visualisation, and dashboard/visual data representation descriptions

In the end-user involvement in dashboard design category, four sub-categories were considered: a) Software development, when papers solely focus on the development of new technology for PD monitoring; b) User validation, when participants (e.g., PD patients, caregivers, health professionals) were recruited and asked to test/use the system; and c) End-user involvement during design, when papers describe the use of co-design or participatory design techniques to inform how clinical data should be visually presented, and d) Longitudinal feasibility study, when end-users use the system for a certain period. For the level of data visualisation category, three sub-categories were considered: a) Basic, when the studies only mention the format in which feedback is given to end-users (e.g., report, a web application); b) Conceptual, when authors report the type of information they would like to visually represent in a dashboard (e.g., number of Freezing of Gait episodes) or use some graphic/visual representation of the data (e.g., a bar chart is used to represent how data can be display) but there is no dashboard; and c) Visual representation, when an interface is presented displaying clinical data after been submitted to some type of statistical analyses.

RESULTS

From the electronic databases search, 1182 records were initially identified (see Fig 1). Twelve records were excluded: ten duplicates and two ineligible records (e.g., retracted paper). After screening for title and abstract eligibility, 1025 records were excluded, leaving 145 records for full-text analysis. Upon full-text analysis, 98 articles were excluded, with the most common reasons being the absence of data visualisation (n = 74), data visualisation presented only during the data extraction phase (i.e., no data visualization related to PD monitoring) (n = 7), study focus was on PD assessment/screening, or the system developed was unrelated to monitoring of PD symptoms (n = 8). Finally, 47 articles met the inclusion criteria, and detailed information on these studies can be found in Table 1. Studies details (n = 47).

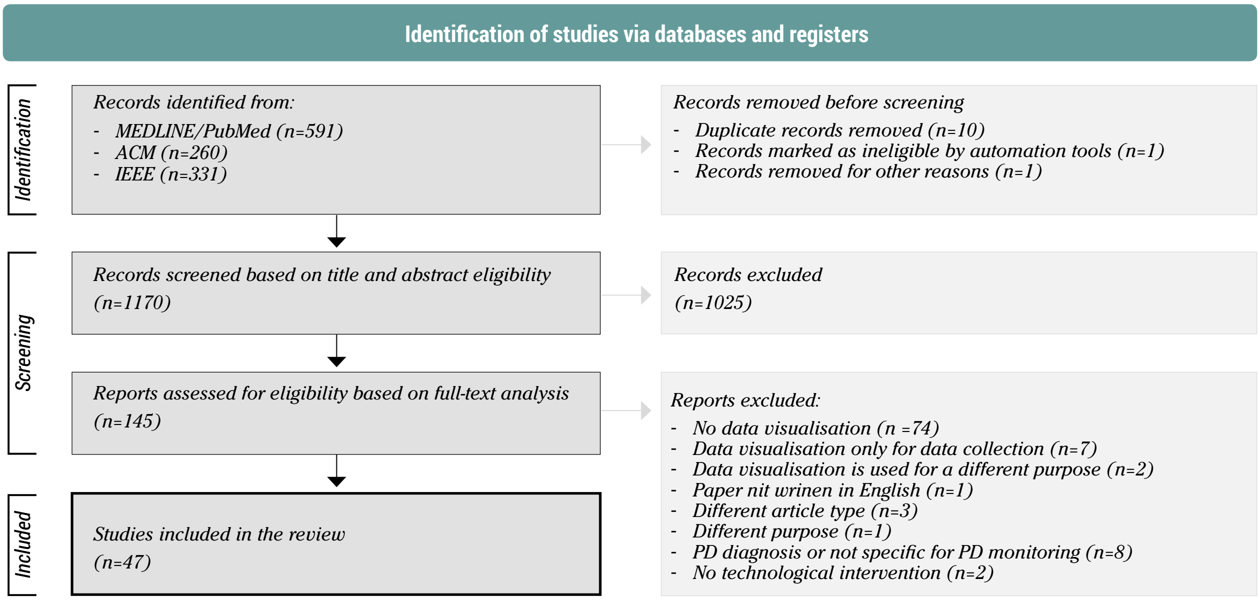

Fig 1. Prisma flow diagram.

TABLE 1. Studies' details (n = 47)

Paper reference	Aim and Context	Health-related outcomes	Technology employed	End-users involvement and methods	Dashboard / data visualization description
Dias et al., 2022 (15)	To test the usability and simplicity of the PDapp system to monitor PD patients in clinical and free-living environments and support clinical decision	On and OFF states Wrist rigidity, Bradykinesia, Gait impairment Falls Tremors	iHandU (wearable device for the wrist), Mobile application Web-based dashboard	***User validation*** ***Participants*** Neurologists assessed both interfaces.	***Visual Representation*** The ***Web-based clinician's dashboard*** is composed of an initial screen divided into four quadrants. In the first quadrant, the patient's details are displayed (photo, name, birthday, the year when symptoms started, and contacts). The second quadrant shows the medication intake for the last seven days using a line graph. Furthermore, information regarding drugs, dosage, and frequency of intake is also displayed. The third and fourth quadrants show a list of the most recent events (i.e., off-state, tremor, difficulty in walking, falls) and the name of the tests performed. On the screen showing tests' results, patient's performance is displayed as percentagens (%) of improvement, duration of the test in seconds, and the max, average and min in dg/s.
Serhani & Chao, 2013 (16)	To develop an end-to-end system for continuous monitoring of PD patients	Tremor	Sensors Accelerometer Wearable EEG monitor, ECoG	***Software development***	***Basic*** A smartphone application will be used to display customised data using a variety of formats, including tables, graphs, and reports.
Seong, Lee, & Kang, 2014 (17)	To develop a watch platform that records the data of the user's daily life activities.	User's daily life activity for diverse services	Sensors Watch	***Software development***	***Visual Representation*** A user interface displays the type and date of different events, such as movement, going out, going home, weight measure, medication intake.
Patil et al., 2022 (18)	To develop smart shoes to detect FoG and falls in PD patients	Freeze of gait Falls	Smart shoes Electromyography Pressure sensors, Gyroscope Accelerometer	***Software development***	***Conceptual*** The ***Blynk app*** displays FoG episodes using a line graph. Every time a FoG episode is identified, the app records the time of occurrence for future analysis and monitoring

TABLE 1. *(continue)*

Paper reference	Aim and Context	Health-related outcomes	Technology employed	End-users involvement and methods	Dashboard / data visualization description
Thinh, Thang & Thanh, 2017 (19)	To develop a self feeding device to support individuals with arm disability in self-feeding activities	Nutritional intake	Robot (FeedBot)	***End-users involved during design*** Patients and caregivers' opinions were taken into consideration during the design of the prototype	***Basic*** Smartphone app show the meal's data as graphs, charts or figures. The data presented regards the meal's nutritional value, favourite food, and meal time. Additionally, it is possible to include remarks and observations regarding user food habits.
Pulliam et al., 2018 (20)	To validate algorithms for continuous simultaneous monitoring of tremor, bradykinesia, and dyskinesia in the context of quantifying levodopa dose response and development of tools for quickly visualizing individualized response patterns.	Tremor, Bradykinesia, Dyskenia	Kinesia motion Sensor units Tri-axial gyroscope and accelerometer	**Software development** **Participants:** 13 PD patients ***Task:*** Six activities of daily living: brushing hair and teeth, dressing, eating, writing on a paper and using a computer, reading or watching tv, folding towels and clothes	**Visual Representation** Radar charts were used to visualize the individualised dose response for each subject across all metrics, bradykinesia score, tremor score, tremor duration, dyskinesia score, dyskinesia duration, at rest. Each axis of the chart represents one of the objective metrics, which range from 0 to 4 for the severity scores and 0 to 100 percent for the duration detected, with larger values indicative of more impairment. The two shaded areas were represented corresponding to metrics extracted from the period before (black) and after (grey) taking medication.
Synnott, Chen & Nugent, 2011 (21)	To assess if an off-the-shelf consumer technology (i.e., Nintendo Wii) provides an intuitive mean of interaction with a package capable of capturing, analyzing, and visualizing a wide range of motor and non-motor metrics	Tremor, Slowness of movement Reduce fine motor coordination	Nintendo Wii 3-axis linear accelerometer front-facing infrared camera	***Software development*** ***Participants:*** 5 healthy individuals ***Task:*** Mini-games similar to tasks carried out during a clinical assessment (e.g., Target Shooting, Target Holding, Target Following, Button Tapping (prompted), Button Tapping (unprompted), Target Sorting	***Basic*** A ***visualization engine*** which displays and summarises the relationship between metrics in a technical manner for clinicians and a non-technical manner for patients and other stakeholders.
Ho et al., 2024 (22)	To showcase the suitability and efficiency of a platform that enables the recording and uploading of gait trial data seamlessly from any location.	Gait parametrs: Stride length, Stride width, Stride time, Velocity, Cadence	2D and 3D data from a binocular 3D camera for monitoring and analysing gait parameters.	***User validation*** ***Participants:*** 122 PD patients and 224 healthy subjects ***Task:*** 8-meter walking test	***Visual Representation*** ***Clinicians' interactive dashboards*** are composed of three working areas. On the left section of the screen (1/3) is displayed the patient profile, including name, gender, birthday, diagnosis, stage of disease, and additional information In the upper right section of the screen, there is a line graphic that shows the last scores obtained on the last assessment moments in different gait parameters (i.e., stride length, time, velocity, cadence turn time). In the downright section of the screen, is shown the score obtained on the same gait parameters, together with videos of the exercises.
Rigas et al., 2009 (23)	To developed a system that monitor, assess and propose treatment plans to PwP	Tremor	Smartphone sensors Accelerometer	***Software development*** ***Participants:*** 5 health subjects (i.e., medical doctors) assessed both interfaces. ***Task:*** Subjects were equipped with the sensors and asked to simulate Parkinsonian tremors with a severity of 1 to 4.	***Basic*** ***PERFORM*** system is composed of two interfaces: The clinician interface, enables healthcare professionals to evaluate the patient's disease features, evolution over time, personalized patients' treatments and medication schedules and generate statistical information. Patient management interface, which is responsible for the identification and quantification of the patient's symptoms and the recording of other useful information related to the evaluation of the patient's status, such as patient activities.
Madani, Lohi & Lohi, 2010 (24)	To developed a system that monitor, assess and propose treatment plans to PD patients	Tremor, ON and OFF states, Drug-induced dyskinesia, Falls, Galvanic Skin Response, SpO2, Pulse rate	Sensors Accelerometers, Gyroscopes, Galvanic Skin Response, SpO2 Pulse	***Software development***	

TABLE 1. *(continue)*

Paper reference	Aim and Context	Health-related outcomes	Technology employed	End-users involvement and methods	Dashboard / data visualization description
Megalingam et al, 2014 (25)	To facilitate communication between a wearable health monitoring system and the external world with a smartphone.	Heart rate, Blood oxygen saturation, ECG, Temperature, Respiration rate, Tilt, Fall	Sensors	***User validation*** ***Participants:*** 6 subjects ***Task:*** ECG measured with sensor	***Basic*** A ***customizable application software*** will be developed which will provide specify critical limits and values beyond which an alert mechanism is triggered.
Ryder et al., 2009 (26)	To develop an application that infer user's transportation mode (walking, running or stationary)	Mobility patterns	Mobile phone sensors Accelerometer GPS	***Software development***	***Visual Representation*** A ***web-based application*** provides a daily snapshot of user's ambulatroy activity. Through this app data is available to the user, user's family, friends or caregivers. In addition a ***Daily trace calendar*** displays the user's location traces for each day in a monthly calendar.
Patel et al., 2010 (27)	To develop a longitudinal home-monitoring system of PD patients	On and OFF states Dyskinesia, Bradykinesia, Tremor	Wearable sensors Tri-axial accelerometers Video conference server	***Software development***	***Visual Representation*** ***MercuryLive, a web-application*** The platform provides access to sensor data and supports live video communication between clinicians and patients during motor exercises. A GUI displays live decimated motion signals alongside the video session to allow clinicians to view and annotate data during each remote supervised data collection session. The GUI also enables the inclusion and selection of specific daily life activities exercises (i.e., motor tasks), displaying the time spent on each task. Clinicians can also download long-term data to allow customised rigorous data analyses
Chen et al., 2010 (28)		Motion data		***Software development*** Patients' data were collected for three hours during the performance of 100 planned tasks	
Patel et al., 2011 (29)				***Software development*** ***Participants:*** 5 PD patients were recorded over a period of three days (two days in a clinical setting and one day in a home setting). ***Task:*** Two tasks from UPDRS (i.e., heel tapping with left and right leg and alternating hand movement (pronation/supination with left and right hand)	
Zhang et al, 2011 (30)	To monitor PD remotely, record and analyze functional activities, and provide accurate real-time feedback with a smartphone. Three studies were conducted.	Standing, Sitting, Lying, Walking, Sit-to-stand and stand-to-sit transitions	Three sensors Accelerometer Gyroscope	***User validation*** ***Participants:*** Study 1: n/a Study 2: n/a Study 3: 10 healthy young subjects ***Task:*** Study 1: System validation Study 2: System validation Study 3: Functional activities trials	***Basic*** ***Functional Activity Monitor system*** The smartphone stores data, analyzes data online, provides feedback to the user and update results to the health care center through either an Internet or cellular connection.
Gatsios, Rigas & Konitsiotis, 2021 (31)	To identify the core requirements of the PRIME CDSS functionally and dashboard	Tremor, Dyskinesias	Smartphone, Smartwatch, Pair of smart insoles	***End-users involved during design*** ***Participants:*** Movement disorders experts and 2 experienced software engineers ***Task:*** Expert discussion until a consensus was reached	***Conceptual*** *UR1* - Offer discrete and standardized neurologic examination documentation options *UR2* - Enable tracking of changes to neurologic examination findings or severity *UR3* - Automatically integrate patient portals and import patient-reported outcomes *UR4* - Incorporate PD-specific clinical data (neuroradiology, neurophysiology) *UR5* - Present to the clinicians similar patients' cases to the one being assessed *UR6* - Provide clinicians with suggestions based on Guidelines (MDS, NICE) to guide their diagnosis, visualizing relevant historical data, e.g. from motor fluctuations *UR7* - Show non-motor and motor symptoms in common and informative graphs, whenever possible *UR8* - Provide drill-down capabilities to enable clinicians to get insights into specific timeframes, e.g., using a calendar-like module, also supporting comparisons

Continue →

TABLE 1. *(continue)*

Paper reference	Aim and Context	Health-related outcomes	Technology employed	End-users involvement and methods	Dashboard / data visualization description
					UR9 - Present in a single view info for symptoms and medication adherence to correlate them *UR10* - Present the specific symptoms, comorbidities and timeframes of interest for each patient instead of providing standardized views *UR11* - Provide a tool with medication options based on MDS and other evidence-based clinical Guidelines to support treatment decisions *UR12* - Include drug-drug interactions, drug-gene interactions, drug-protein interactions (whenever data on genetics is available) to support prescribing. *UR13* - Include the up-to-date list of the prescribed pharmacotherapy and supporting therapy plans *UR14* - Include adherence to pharmacotherapy and supporting therapy plans. *UR15* - Enable the monitoring and evaluation of changes in the pharmacotherapy and supporting therapy plans to provide an improved treatment plan *UR16* - Provide (optionally) ecologically valid summary activity and sleep data. *UR17* - Support data sharing between clinicians *UR18* - Enable data sharing among clinicians involved in the multidisciplinary care of patients (where applicable).
Fei et al, 2020 (32)	To collect data, real-time data display, and data analysis using a wearable health monitoring system	Heart rate, Blood pressure, Step count	Wrist band with Sensors Accelerometer Gyroscope	***Software development***	***Conceptual*** ***Wearable health monitoring system*** This system includes a complete method for monitoring heart rate, real-time displaying, history data recording and transmitting important data to the mobile phone for further analysis. In addition to the heart rate monitoring, other features such as step counting, abnormal gesture detection and falling detection are also included, and users can classify abnormal gesture and trained off-line.
Pierleoni et al, 2019 (33)	To monitor and automatically evaluate PD with wearable devices to support medical evaluation using visualization and classification of data collected.	Tremor, Freeze of gait	Wrist band Accelerometer Gyroscope Magnetometer	***User validation*** ***Participants:*** 60 participants (healthy subjects and PD patients) Tremor: 40 Freezing: 10 Remote: 10 ***Task:*** Clinical assessments (Index-nose test, Timed Up and Go, transit through a narrow passage, transit through a door that end by sitting and on a chair)	***Conceptual*** The system for remote monitoring allows both the doctor and the patient to access the daily view of the patient's clinical status and the history of tremor and FoG episodes recorded during the monitoring period. In addition, it is also possible to automatically generate a spreadsheet showing the significant events of the day.
Jusufi, Nyholm & Memedi, 2014 (34)	To present interaction and visualisation approaches used to aid clinicians in the analysis of repeated measures of spirography of PD patients	Motor fluctuations between On and Off states in dyskinesia symptoms	Touch screen device	***Software development***	***Conceptual*** The overall visualization helps the clinicians discover different kinematic features of the PD patients. The two views (spiral and time series plots) are coordinated and linked, enabling the user (clinician) to explore the data in more detail. This enables the user to investigate data at specific time points in one view in context of the other.
Santos et al, 2019 (35)	To monitor gait in PD patients and assist healthcare professionals with reports of the collected data	Gait patterns	Shoe insole Sensor Vibration	***Software development***	***Conceptual*** A smartphone application with graphics and images is available for the healthcare professionals to consult the patients' history information. In the initial screen the app also informs the most frequent type of classification and the status of the evaluation of the gait training. In the history menu, the healthcare professional has the option to consult in three ways: Daily, Monthly, and Weekly.

TABLE 1. *(continue)*

Paper reference	Aim and Context	Health-related outcomes	Technology employed	End-users involvement and methods	Dashboard / data visualization description
Polychronidou et al, 2024 (36)	To present the HealtVision	Heart rate Saliva Activity Social and Psychological data	Sensor	***Software development***	***Conceptual*** Visualizations of the data collected using scatter-plots, line plots, graph-based plots, among others. Also it is presented a map between different feature type and the most relevant visualization category.
Solachidis et al, 2021 (37)	To improve quality-of-life in Pd patients and facilitate healthcare professional in obtaining objective data regarding movement evolution	Heart rate, Steps, Motion data, User activity, Sleep analysis, Fall,	Multisensory band (bracelet) Localization Sleep Tracker, Microphone, RGB-D, Accelerometer	***Software development***	***Conceptual*** ***TENDER rehabilition tool user interface*** The main focus is personalizing services and functions to: i) Patients by providing personalized recommendations, ii) Caregivers by helping them understand patient situation and providing suggestions on care steps to take into account and information to review iii) Professionals by highlighting patient key information to have an overall picture of patient data.
Belmonte-Hernandez et al, 2019 (38)				***Longitudinal feasibility study*** ***3 months per participant*** ***Participants:*** 30 participants (6 physiotherapists, 12 controls, 12 PD patients)	
Kumar et al, 2023 (39)	To monitor PD remotely with an application	Tremor, Bradykinesia, Balance	Smartphone Accelerometer Gyroscop	***Software development***	***Conceptual*** The user interface component provides a visual representation of the detected tremors, along with additional information or feedback for the user. The interface enables the user to interact with the software and review the results.
Fadhlannisa & Basari, 2020 (40)	To develop an electromyography based remote-monitoring system so	Muscle activity of Parkinson's disease patients	Sensors NodeMCU-based wireless EMG device	***Software development***	***Conceptual*** ***EMG monitoring system display interface,*** showing EMG amplitude through a line graph in the upper part of the screen, and a 2x2 table showing time and EMG value in the bottonm part of the screen. The monitoring system program can also be accessed via smartphone.
Bernardini et al., 2018 (42)	To collect motor and non-motor PD symptoms and improve communication with specialists	Apathy, Depression, Non-Movement Problems, Movement Problems, Health Status, Pain	ePROs	***Longitudinal feasibility study*** Every 2 months for 1 year ***Participants***: 10 PD patients and 7 caregivers ***Task:*** Apathy Survey, Depression Survey, Non-Movement Problems Survey, Movement Problems Survey, Parkinson's Disease Survey, Health Condition Survey, Pain Condition Survey, Caregiver Burden Survey	***Conceptual*** A ***visual characterisation of users*** is displayed using a 3x3 table with Patient ID, a qualitative assessment of scores obtained in the surveys filled in (e.g., Normal/ Warning). The warning is specific for the set of surveys filled in and is indicative of symptoms worsening (e.g., PSY Warning).
Gugliandolo, et al., 2019 (43)	To develop a system which is wearable, able to record, store, and wirelessly transmit three-axial acceleration data, and it can track the GPS position of the patient wearing it.	Tremor	Sensors Four accelerometers connected to an embedded development board	***User validation*** ***Participants:*** 2 PD patients and 1 healthy subject with 40, 62, and 54 years old, respectively ***Task:*** 1 PD patient - to hold the system in their hand, and then hold a pen; 2 PD patients - to put their hand in two positions	***Visual Representation*** A ***web app*** shows the data acquired, plotted in real-time, and some statistics. In the upper part of the screen is shown the three sensors' signals using a three-line graph. In the bottom section, the patient's current location is shown on a map, and some statistics, such as the number of hours walked and the estimated frequency of each channel is displayed.
Wagner & Ganz, 2012 (44)	To develop and test a portable and accurate gait analysis system, that enables patients to monitor their gait and track progress and improvement over time.	Gait patterns (i.e., stride time, swing time, stance time, stride time variability, step time balance)	Shoe insole Two microcontroller Android Smartphone	***Software development***	***Visual Representation*** The smartphone analyzes the raw data to produce temporal gait parameters that are displayed to the user on a graphical user interface.

TABLE 1. *(continue)*

Paper reference	Aim and Context	Health-related outcomes	Technology employed	End-users involvement and methods	Dashboard / data visualization description
Cunha et al., 2016 (45)	To present a novel portable, low-cost kinect-based system that aims to enhanced the typical patient monitoring and assessment methods used in clinical practice and research	Gait parameters	RGB-D camera (Microsoft Kinect) Two integrated software applications, KiT (KinecTracker) and KiMA (Kinect Motion Analyzer	***Software development*** ***Participants:*** Study 1: 3 PD patients treated with deep brain stimulation and 3 healthy subjects; Study 2: 4 PD patients and five non-PD patients ***Task:*** Single task performed in a hospital setting	***Visual Representation*** KiMA interface allows the storage and replay of video records of patients. KiMA also facilitates the management (creation, edition and deletion) of labels and events for the identification of movements of interest (MOIs), with this information being visually displayed above the video. Furthermore, events can be exported as segments of the original data acquisition, enabling their review on a dedicated workstation.
Lin et al., 2016 (46)	To develop an algorithm to evaluate the severity of festinating gait behaviour.	Festinating Gait	A posture monitoring vest with multiple 3-axis accelerometers	***Software development*** ***Participants:*** % healthy subjects	***Visual Representation*** A ***mobile app*** was developed so each individual can review their gaiting behaviour in the past 9 months. A three-line graph is used to display the average and stand deviation stepping frequency, ratio index, and the upper body lean forward angle
Bourazeri & Stumpf, 2018 (47)	To co-design a user interface of a self-care smart home technology toolset with people living with PD and their caregivers using the PERCEPT approach. Four workshops were conducted	Well-being and quality of life. Physical and psychological outcome	Tablet	***End-users involved during design and User validation*** ***Participants:*** 6 PD patients (first workshop), 5 afterwards; 4 PD (first workshop) 3 afterwards. Two different sessions with each group ***Task:*** 4 workshop session. Empathy probes between W1 e W2 to self-report on their daily activities	***Conceptual*** Tablet interface focusing on different tasks such as set-up a profile, a life plan, sharing of their data with others, and how to monitor their life plan.
Zhang et al, 2020 (48)	To assess the first smartphone-based system to detect drug effectiveness among PD patients in daily life	Talking, Walking, Standing Symptom severity	Smartphone Microphone Accelerometer, Gyroscope	***Longitudinal feasibility study*** 6 months ***Participants:*** 81 PD patients ***Tasks***: Voice, walk, and standing activity	***Basic*** A feedback report is provided.
Lennon et al, 2015 (49)	To remotely monitor dyskinesia in PD remotely	Dyskinesia, Tremor	Sensors Accelerometer Gyroscope Smartphone	***Software development***	***Basic*** The data collected is processed and available for evaluation by a physician to help monitor dyskinesia severity.
Pereira et al, 2015 (50)	To facilitate comunication between patients and healthcare professionals with an application to monitor PD in free-living.	Medication and personal notes for PD Healthcare professional can prescribe mediciation plans and notes	Mobile application	***End-users involved during design*** ***Participants:*** 36 participants (11 PD patients, 11 caregivers, 14 healthcare professionals) ***Task:*** Fill in a survey	***Basic*** PD patients can visualize their personal notes, medication and receive alerts. Healthcare professionals can visualize patient's notes, prescribed medical plans and exercises.
Branco et al, 2019 (51)	To design a web-platform containing personalized reports of inertial sensor data. Two studies were conducted	Physical activity, Energy spent, Sleep analysis	Wrist band Inertial sensor accelerometer	***End-users involved during design*** ***User validation*** ***Participants:*** Study 1: 5 participants (1 neurologist, 2 physiotherapists, 2 nurses); Study 2: 25 particiopants (22 PD patients, 4 healthcare professionals) ***Tasks:*** Study 1: focus group and a design workshop; Study 2: PD patients used the device during 3 or 7 days, 4 healthcare professionals used DataPark	***Visual Representation*** Each report is composed of a set of charts, tables, and measures that give a processed analysis of the raw data. The information shown is about physical activity, energy spent, and sleep. They used different types of views for data, for example, by day, week, or period of the day. If needed, clinicians can adjust each report according to the patients or the type of analysis they want to see or discuss.

TABLE 1. *(continue)*

Paper reference	Aim and Context	Health-related outcomes	Technology employed	End-users involvement and methods	Dashboard / data visualization description
Dubey et al., 2015 (52)	To assess the performance of EchoWear, a smart-watch-based system, to remotely monitor speech and voice exercise	Speech/ dysarthria	Smartwatch Microphone	***Software development*** ***Participants:*** 3 PD patients and 3 healthy subjects ***Task:*** Three speech tasks. *Task 1* - vowel prolongation task, *Task 2* and Task 3 were developed to record high and low pitches	***Conceptual*** The system uses large amounts of speech quality metrics (SQMs) computed over time, including average loudness level in dB (Phon) and average fundamental frequency (Hz) to provide automatic health reports to the speech-language pathologist and/or participants, using for instance bar charts.
McNaney et al, 2022 (53)	To explore que perceptions of PD patients and their caregivers about sensors and how data collected from these devices can be visualized. Two studies were conducted.	Activity, Temperature, Parkinson's symptoms	Sensors Accelerometer Environmental sensors Silhouette video Cameras Smart home sensors Mechanical flow sensors Wearable device	***End-users involved during design*** ***Participants:*** *Study 1:* 12 participants (6 PD patients and 6 caregivers); *Study 2:* 8 participants (4 PD patients 4 and caregivers) ***Task:*** *Study 1:* 2-hour session at a smart home equipped with sensors to complete a set of activities (meal preparation, cleaning, sleep-related activity, washing up and resting; *Study 2:* 2-hour workshop to show garaphical data visualization of the sensors 'outputs.	***Conceptual*** From the workshop discussion around data visualization from sensors, participants reflected about personal data opportunities for data usage, trust and transparency, data misued, and for-profit data.
McNaney et al, 2015 (54)	To develop and evaluate LApp, an application for Google Glass to help PD patients monitor their speech volume and cue themselves to speak louder when necessary. Three studies were conducted.	Vocal volume	LApp on Google Glass	***End-users involved during design*** ***User validation*** ***Participants:*** *Study 1:* 7 PD patients; *Study 2:* 8 Healthy subjects; *Study 3:* 6 PD patients ***Task:*** *Study 1:* Exploratory design workshop; *Study 2:* Test the application in a 30-minute session; *Study 3:* 3 days usage of LApp on Glass to explore PwD experiences using the app.	***Conceptual*** During the workshops different types of cues were suggested by participants (visual, haptic and auditory). There was some disagreement in relation to what would be preferred, with some suggesting audible cues that only they could hear, and others preferring visual or haptic cues they could respond to. Participants came to an agreement that cue preferences depended on context, but all felt comfortable with the idea of using a 'traffic light' style visual cue shown directly on Google Glass.
Chuang et al, 2010 (55)	To promote patient-centered healthcare and self-management with monitoring devices.	Blood pressure, Weight	Blood pressure monitor, Digital weight scale	***Software development***	***Visual Representation*** The system can display graphs that show the gradual progression of the measurements over weeks, months or years. The patient can identify whether the measurements are normal by the colors of the graph's points (green means normal, yellow means warning, red means attention is required). If the patient clicks on a point on the graph, the actual measurement and an "analysis message" appears in the left column.
Zhu et al., 2016 (56)	To assess the feasibility of computer vision-based gait analysis system	Gait analysis	Camera of a mobile phone	***Longitudinal feasibility study*** 2 weeks ***Participants:*** 55 elderly subjects, 44 PD patients and 11 healthy controls ***Task:*** Walking from left to right, turning around at the end and walking back	***Conceptual*** To provide information to doctors or clinicians, the system is able output the subject's basic statistical information, including mean, coefficient of variation, and standard deviation of left and right stride lengths and times.
McNaney et al., 2016 (57)	To evaluate how the provision of feedback, using apeeching, was valued by PD patients.	Speech Articulation, Volume Rate Pitch variability	Mobile phone	***Longitudinal feasibility study*** 1 week ***Participants:*** 6 PD patients [61 - 74 years] ***Task:*** Patients' speech samples (e.g., reading 10 single words and reading sentences, describing a picture or answering an open question. Finally, there is a combination of reading words and free speech)	***Visual Representation*** The ***Speeching app*** enables users to receive feedback on their speech and allows for the self-directed practice of speech issues common to PD. Patients are provided with a graph of their Ease of Listening (EOL) score over time, the EOL score of the sample they have just submitted, along with its volume, rate and pitch scores. Users are advised that both volume and pitch scores should fall within 50 and 90, while scores for rate should be between 40-60.

TABLE 1. *(continue)*

Paper reference	Aim and Context	Health-related outcomes	Technology employed	End-users involvement and methods	Dashboard / data visualization description
Lipsmeier, Florian, et al, 2018 (58)	To determined the feasibilty, reability, and validity of digital biomarkers during a 6-month clinical trial of individuals with PD patients. Two studies were conducted	Tremor Bradykinesia Rigidity/postural instability	Smartphone app (Roche PD mobile application) IMU sensor (accelerometer, gyroscope, magnetometer) Voice recorder	***Longitudinal feasibility study*** *Study 1:* 6 month *Study 2:* 6-week observational ***Participants:*** *Study 1:* 43 PD patients; *Study 2:* 35 Healthy match controls ***Tasks:*** 6 active tests + passive monitoring (walking, s2s, walking)	***Conceptual*** An image of the ***Roche PD*** mobile application shows that users have access to overall progress of the completed days of active testing and the amount of hour. The overall progress is displayed in a donut chart.
Barros et al, 2013 (59)	To design and evaluate a PD self-management approach with four smartphone applications.	Personal information, Blood type, Medication, Medical condition Adhrence and prescription list	4 Smartphone applications	***End-users involved during design*** ***User validation:*** *Interviews* – 5 PD patients, 1 informal caregiver, 1 physical therapist; *Scoping session* – 3 PD patients, 3 informal caregivers; *Focus group* – 2 PD patients, 2 informal caregivers; *User cases* – 3 medical doctors; *Second Part* – Software development; *Third Part* – User validation with usability test	***Conceptual*** ***REMPARK system*** is composed of different applications: medication, appointments, my day (disease status/symptoms), my data (personal and health information), messaging, calling, emergency call, contacts, two cueing controllers to improve users's gait, and medical questionnaires In my day app, a 24h clock graph is displayed showing freeze of gait, festination, diskenesia and failure in medication intake using flags.
Isaacson et al, 2019 (60)	To investigate whether using Kinesia 360 at home could improve motor symptom management in PD patients starting transdermal dopamine agonist rogigotine	Tremor Slowness, Dyskinesia Walking severity	Kinesia 360 mobile application motion sensors Kinesia ONE mobile application finger or heel motion sensor to colllect data	***Longitudinal feasibility study*** 12 week ***Participants:*** 39 PD patients (20 control group and 19 experimental group) ***Tasks:*** *Experimental group:* used Kinesia 360 to perform health related assements; *Control group:* did not use kinesia 360 and were only provided with standard care. Both Groups used kinesia ONE at day 1 and week 12 to measure motor assessment performance during specific motor tasks	***Conceptual*** ***Kinesia 360 smartphone app*** provides data reports for patients about the health-related outcomes. For walking severity display a traffic-light analogy is used.
Belmonte-Hernandez et al, 2022 (61)	To develop a system to collect raw information. Three studies were planned (two were conducted).	Sleep Daily activities Steps Freezing, Bradykinesia Gait festination Walking Balance	Smartwatch, Door sensor Smartphone, Depth Sensor	***User validation*** ***Participants:*** PD patients, caregivers, healthcare professionals ***Task:*** *Study 1:* Use web and mobile application; *Study 2:* Use different devices and configurations; *Study 3:* Use all the available features for the platform	***Visual Representation*** ***ProCare4Life system Web Interface*** to be used by healthcare professionals to manage and monitor their patients. It has a dashboard available with charts and metrics. A mobile application enables patients to access and manage their data in the PROCare4Life platform. Smart TV Cognitive Gaming Tool provide cognitive games and questions to create an experimental screening tool that will be used to assess the cognitive abilities of patients.

Legend: ***ECG*** *– Electrocardiogram;* ***EcoG*** *– Electrocorticography;* ***EEG*** *– Electroencephalography;* ***EMG*** *- Electromyography;* ***FoG*** *– Freezing of Gait,* ***GUI*** *– Graphical User Interface;* ***PD*** *– Parkinson's Disease;* ***SpO2*** *- Peripheral capillary oxygen saturation;* ***UPDRS*** *- Unified Parkinson's Disease Rating Scale.*

TECHNOLOGIES AND DEVICES FOR PD MONITORING

Patients' data were collected using various technologies, including sensors directly attached to the participant's body (16, 20, 24, 25, 27-30, 36, 40, 43, 48, 49, 53, 60), integrated into smartphones (23,26,39), or incorporated into accessories, such as wristbands (15, 17, 32, 33, 37, 38, 51, 61), smart shoes (18), smart glasses (54), shoe insoles (31, 35, 44), or clothing (41, 46).

Other types of devices used for data collection included a blood pressure monitor and a digital balance (55), gaming consoles (i.e., Nintendo Wii) (21), tablets (34, 47), video cameras (22, 45, 56) voice recorders (52, 57), and mobile applications (50, 58, 59).

Additionally, one study employed a robot to assist in feeding patients with motor impairments (19), and another utilized ePROs for data collection (42).

HEALTH-RELATED OUTCOMES

As a central criteria of the present review, all studies included focused on technologies that enable the monitoring of PD patients. Among the health-related outcomes, motor symptoms of PD were the primary focus in 39 out of 47 studies. The predominant motor symptoms analysed were tremor (15, 16, 20, 21, 23, 24, 27, 31, 33, 39, 41, 43, 49, 50, 60), bradykinesia (15, 20, 21, 27, 38, 39, 49, 58), dyskinesia (20, 24, 27, 31, 34, 49, 60), wrist rigidity (15), fine motor coordination (21), tilt (25), and balance (38, 39, 58). Additionally, other studies examined motor fluctuations between the On and Off states (15, 24, 27, 34) associated with the intake of levodopa (20).

Distinctive features of PD associated with impaired walking capacity were also analysed (15), including FoG (18, 33, 38), falls (15, 18, 24, 25, 37), and gait festination (38, 46). Other studies focus on speech impairments, including dysarthria (52), variations of the vocal volume (54, 57), articulation, and rate and pitch variability (57).

Another group of studies opted to focus not on clinical symptoms but rather on motor metrics/gait parameters, including but not limited to stride length, stride width, stride time, velocity, cadence swing time, step count (22, 26, 28, 29, 32, 35, 37, 38, 44, 45, 48, 56), physical activity (51) and user's capacity to execute motor tasks (30, 48), including standing, sitting, lying, and walking as mean to assess and monitor the progression of PD motor symptoms.

Physiological data considered in some of the studies included were: heart rate (25, 32, 36, 37), galvanic skin response (24), blood pressure (32, 33), blood oxygen saturation (24, 25), pulse rate (24), EEG (16) and ECoG (25), EMG (40), temperature (25, 53), respiratory rate (25), saliva (36), and sleep parameters (37, 38, 51).

Studies focused on non-motor aspects were less frequent (8 out of 47) and primarily investigated nutritional intake and patients' capacity to feed themselves (19), medication intake (50, 59), capacity to perform daily life activities (17, 38), health status, including pain, depression and apathy (42), social and psychological health (36), well-being and quality of life (47).

DATA VISUALIZATION

When it comes to providing end-users with feedback on the collected data, three levels of data representation were identified: basic, conceptual, and visual representation. Among the studies included, 10 articles were classified as offering a basic description of how data is visually presented to end-users. In these cases, the studies only mentioned the format of feedback provided to end-users without delving into specifics. Of these, two studies simply mentioned that some form of feedback is provided to end-users without providing further details (49, 50). One study specified that a report is provided to end-users (48), while four studies utilized a customizable application/interface (21, 23-25). Additionally, three studies indicated that feedback is delivered through a smartphone application (30), with two of them mentioning that tables, graphs, charts, reports, and figures can be used for visually displaying the data (16, 19).

On the other hand, 21 articles were classified as describing the type of data displayed without a dashboard having been developed (i.e., conceptual). Among these, 10 studies (31-33, 37-39, 41, 47, 53, 56) just mentioned the type of data that ideally would be reported to end-users. For more details on the data considered in these studies, see Table 1. Studies' details (n=47). The remaining 11 studies provide a more detailed description of how data will be presented. For instance, Jusufi, Nyholm and Memedi (34) considered using spiral and time series plots to visually represent motor fluctuations over time. Tables (35, 42) and donut charts (58) were mentioned in three studies as a possible way to visually display data when patients performed motor tasks and the results obtained on those tasks. Line and graph-based plots were mentioned to display physiological data such as EMG (40), and heart rate (36), respectively. Patil et al. (18) mentioned using line graphs and dates to report FoG episodes, while Barros et al. (59) used 24-hour clock graphs with different time flags to report the occurrence of FoG, festination and dyskinesia episodes and patients' compliance with medication schedules. Finally, in studies focused on speech impairments associated with PD, bar charts (52) and a traffic-light-based graph (54) were presented as suitable forms to represent speech quality and volume, respectively. Isaacson et al., (60) also propose the use of traffic-light-based graphs to visually display gait impairment.

Finally, more complex and detailed forms of data visualization (i.e., dashboards) were identified in 16 of the studies included. For instance, in two of these studies, specific sections of the dashboard were reserved for patient's personal information, such as name, photo, birthday, year of symptoms onset, and contacts (15,22). Furthermore, information regarding medication, dosage and frequency was also considered relevant to be present in clinical dashboards aiming at monitoring PD patients, with this data presented either in list format (17), or alongside the patient's personal information (15).

To provide feedback on the occurrence of PD-related symptoms such as tremors, difficulty in walking, falls, and OFF states, lists with dates and time of the event were used (15). Improvements in PD-related symptoms were represented in three studies using percentages (15), line graphics (22) or radar charts where the severity of symptoms (e.g., tremor duration, dyskinesia) before and after medication intake was simultaneously displayed (20).

Gait behaviour (e.g., step frequency) and motor activity metrics such as stance time, swing trace, and step time balance were displayed using line bars (46) or percentages (44), respectively. Additionally, in Branco et al., (51) visualization formats such as charts and tables were identified as suitable formats to display patients' information regarding physical activity, energy spent and sleep.

Regarding video platforms, five studies focused on systems that enable clinicians to watch patients performing motor activities online (27–29) or offline (22, 45), alongside the metrics and results obtained in the motor tests and information if the patient was in the ON or OFF state while performing the tests (22). Furthermore, these platforms enable clinicians to take notes and create and edit labels to identify movements of interest (27–29, 45).

Other data considered in the dashboards analyzed included giving feedback on user location traces using maps (26, 43) or by showing events of interest in a list format (e.g., go home) (17). One dashboard also presented physiological using a three-colour graphic, where green is indicative of levels within normal parameters, yellow means caution, and red is indicative that professional assistance should be sought (55). Dashboards dedicated to reporting speech metrics used circular graphs showing the score obtained in each metric as a percentage using Arabic numerals (57). Finally, in one study (61), while a screenshot of a dashboard is provided, the low image quality couple with the lack of description regarding the data and visualization techniques used, renders it challenging to analyse the depicted elements thoroughly.

DESIGN AND VALIDATION OF CLINICAL DASHBOARDS

Out of the 47 studies included in this review, only 22 studies include stakeholders (i.e., health professionals, PD patients, caregivers) and/or healthy subjects in the design process clinical dashboards and validation of the system developed.

User validation was reported in 14 studies. Of those, in seven studies, participants were invited to test the feasibility of the system for a single session (15, 22, 25, 30, 33, 43, 61), while in another seven studies, participants were asked to use the system for longer periods (38, 48, 56, 58, 60), ranging from one-week (57) to every two months for one year (42).

Regarding the design process of the clinical dashboards, only eight studies reported following a co-design/participatory design approach during the development of the clinical dashboard for monitoring PD patients. Nonetheless, the degree of end-user involvement also varied across studies. For instance, in Thinh, Thang & Thanh, (19) it is reported that "patients and caregivers' opinions were taken into consideration during the design of the prototype". However, it does not mention how these opinions were collected or how they contributed to the design of the final dashboard. In Pereira et al., (50) a survey was filled out by 36 participants, including PD patients, caregivers and health professionals, aiming to characterize participants' profiles and identify the needs and functionalities they identified as relevant to have in the app for monitoring of PD. Other forms of end-user involvement in the design process of clinical dashboards for PD monitoring were the conduction of focus groups (51) and Delphi panels (31) bringing together experts in PD and software development engineering. Finally, the conduction of workshops (47, 51, 53, 54) and interviews (59) aiming to identify the needs and elicit hypothetical scenarios that could support the design of clinical dashboards were also reported in five studies.

DISCUSSION

In this study, we conducted a systematic review of the literature to identify, analyse, and synthesise the available research dedicated to the development of data visualisation techniques and dashboards for PD monitoring.

Regarding technologies and devices used for PD monitoring, our findings revealed that sensors embedded in various devices are currently a prevailing trend for data collection (present in 33 out of 47 studies included). Through the use of these devices, data collection can be done in a non-invasive manner, either in an active way, requiring patient intervention (e.g., performing tasks like finger tapping) (62), or passively, utilizing only the device (e.g., ambient sensors) (63). Nonetheless, scientific literature indicates that sensors that enable data collection in a passive way are more easily accepted by end-users (3), and so future research would probably evolve around the development of this type of sensor.

Another trend identified in our study was the focus on developing technology that primarily collects and analyses data related to PD motor symptoms. Parkinson's Disease is characterized by the presence of both motor and non-motor (e.g., cognitive) impairments. However, most studies included in our review (39 out of 47 studies) focused on PD motor symptoms such as tremors, bradykinesia and dyskinesia, among others. Only a small portion of the studies analysed (8 out of 47 studies) focused on PD non-motor symptoms, such as depression, apathy, quality of life and well-being. This finding may reflect a preference for parameters that are the most easily measurable. However, this finding also highlights that there are still plenty of opportunities to be explored in other areas of research, including daily living (34, 39), which are also heavily dependent on cognitive health and may have a direct impact on people's quality of life (64).

In the clinical context, dashboards can play a significant role in facilitating the continuous monitoring of changes in a patient's health status (65,66). However, at a moment where digital devices generate vast amounts of data, the challenge resides in how this data can be digested to facilitate interpretation and practical use in clinical settings (12).

While the concept of data visualisation was ubiquitous across all articles, the extent of its implementation and the level of detail in the techniques employed varied greatly among the studies analysed, with only a small portion (16 out of 47) of the studies included focused on studying and exploring the best ways to consolidate the information collected using an organized visual representation to make interpretation of clinical data simpler and more intuitive (1).

Furthermore, when considering the involvement of end-users in identifying relevant data and determining the best way to represent them, even fewer studies focus on this aspect (6 out of 47). The engagement of end-users, such as in co-design studies, is a crucial component that should not be overlooked, as it impacts technology usage (4). For this reason, involving stakeholders is a fundamental step in defining relevant data and designing platforms and their visualisation formats (67). This is especially true in the healthcare field, where resources are limited and health professionals are in constant demand (68). Therefore, and although the adoption of technology in clinical practice is not always an easy task, it is extremely relevant to improve how data are presented to healthcare professionals to enhance technology's value (68) and optimize clinical decision processes.

LIMITATIONS

The study's results should be interpreted considering some limitations. Firstly, the strategy employed to identify publications, including the keywords used to filter titles/abstracts and the selected collections, may impact the findings. Also, we did not proceed with the analysis of secondary references (e.g., studies included in systematic reviews), which might have excluded potentially relevant papers. Nonetheless, the present results were obtained based on articles identified through searches in three different databases, with some of them highly specialized in software development (i.e., ACM and IEEE). Furthermore, the fact that terms such as monitoring, assessment, evaluation and screening are sometimes used interchangeably in the papers analysed could introduce subjectivity to eligibility criteria and data extraction.

CONCLUSIONS

This study aimed to analyse the available literature on clinical dashboards to monitor PD. Conceptual and dashboards are the predominant visual representations employed. Nevertheless, few studies include end-users during the design process of their systems and visualization platforms, which represents a major shortcoming. Moreover, regarding the data collected and used to populate these dashboards, there is a focus on PD motor symptoms that reflect their importance in disease progression monitoring. This emphasis limits the exploration of other potentially relevant activities that may directly correlate with disease symptoms and is thus relevant to be included in the dashboards aiming to monitor PD patients.

FUNDING
This work was supported by Fundação para a Ciência e Tecnologia through LASIGE Research Unit, ref. UIDB/00408/2020 (https://doi.org/10.54499/UIDB/00408/2020) and ref. UIDP/00408/2020 (https://doi.org/10.54499/UIDP/00408/2020)", Project 41, HfPT: Health from Portugal, funded by the Portuguese Plano de Recuperação e Resiliência, and IDEA-FAST project, which has received funding from the Innovative Medicines Initiative 2 Joint Undertaking under grant agreement No. 853981. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and EFPIA and associated partners.

DECLARATIONS OF INTEREST STATEMENT
The authors report no conflict of interest.

SUPPORTING INFORMATION CAPTIONS
S1 Table. PRISMA 2020 Checklist
S2 Table. Electronic databases and search strategies
S1 File. PROSPERO Protocol

REFERENCES

1. **Sarikaya A,** Correl M, Bartram L, Tory M, Fisher D. What do we talk about when we talk about dashboards? IEEE Trans Vis Comput Graph. 2019;25(1):682–92.
2. **Chiossi F,** Zagermann J, Karolus J, Rodrigues N, Balestrucci P, Weiskopf D, et al. Adapting visualizations and interfaces to the user. IT - Inf Technol. 2022;64(4–5):133–43.
3. **Maetzler W,** Domingos J, Srulijes K, Ferreira JJ, Bloem BR. Quantitative wearable sensors for objective assessment of Parkinson's disease. Mov Disord. 2013;28(12):1628–37.
4. **Iftikhar A,** Bond R, McGilligan V, McShane A, Leslie SJ, Knoery C, et al. Role of dashboards in improving decision making in healthcare: Review of the literature. ECCE 2019 - Proc 31st Eur Conf Cogn Ergon ' 'Design Cogn. 2019;215–9.
5. **Gotz D,** Borland D. Data-Driven Healthcare: Challenges and Opportunities for Interactive Visualization. IEEE Comput Graph Appl. 2016;36(3):90–6.
6. **West VL,** Borland D, Hammond WE. Innovative information visualization of electronic health record data: A systematic review. J Am Med Informatics Assoc. 2015;22(2):330–9.
7. **Milani R V.,** Bober RM, Lavie CJ. The Role of Technology in Chronic Disease Care. Prog Cardiovasc Dis [Internet]. 2016;58(6):579–83. Available from: http://dx.doi.org/10.1016/j.pcad.2016.01.001
8. **Teymourian H,** Tehrani F, Longardner K, Mahato K, Podhajny T, Moon JM, et al. Closing the loop for patients with Parkinson disease: where are we? Nat Rev Neurol. 2022;18(8):497–507.
9. **Janssen A,** Donnelly C, Kay J, Thiem P, Saavedra A, Pathmanathan N, et al. Developing an Intranet-Based Lymphedema Dashboard for Breast Cancer Multidisciplinary Teams: Design Research Study. J Med Internet Res. 2020;22(4).
10. **Helminski D,** Kurlander JE, Renji AD, Sussman JB, Pfeiffer PN, Conte ML, et al. Dashboards in Health Care Settings: Protocol for a Scoping Review. Vol. 11, JMIR Research Protocols. JMIR Publications Inc.; 2022.
11. **Selleck MJ,** Senthil M, Wall NR. Making Meaningful Clinical Use of Biomarkers. Biomark Insights. 2017;12:1–7.
12. **Polhemus A,** Ortiz LD, Brittain G, Chynkiamis N, Salis F, Gaßner H, et al. Walking on common ground: a cross-disciplinary scoping review on the clinical utility of digital mobility outcomes. npj Digit Med. 2021;4(1).
13. **Page MJ,** McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ. 2021;372(n71).
14. **Ouzzani M,** Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan-a web and mobile app for systematic reviews. Syst Rev [Internet]. 2016;5(1):1–10. Available from: http://dx.doi.org/10.1186/s13643-016-0384-4
15. **Dias D,** Silva J, Oliveira N, Massano J, Cunha JPS. PDapp: A Companion Mobile Application with Appcessories for Continuous Follow-up of Parkinson's Disease Patients. In: MELECON 2022 - IEEE Mediterranean Electrotechnical Conference, Proceedings. Palermo, Italy: IEEE; 2022. p. 137–41.
16. **Serhani MA,** Artan NS, Chao HJ. Smart end-to-end infrastructural solution for monitoring patients with neurological disorders. In: Proceedings - IEEE 10th International Conference on Ubiquitous Intelligence and Computing, UIC 2013 and IEEE 10th International Conference on Autonomic and Trusted Computing, ATC 2013. Vietri sul Mare, Italy: IEEE; 2013. p. 644–9.
17. **Seong KE,** Lee KC, Kang SJ. Self M2M based Wearable Watch Platform forCollecting Personal Activity in Real-time. In: International Conference on Big Data and Smart Computing (BIGCOMP). 2014.
18. **Patil KS,** George SM, Naik KG, Chethana P, Kamath N V. Freeze of Gait and Fall Detection in Parkinson's Patients. In: 4th International Conference on Circuits, Control, Communication and Computing, I4C 2022. IEEE; 2022. p. 245–9.
19. **Thinh NT,** Thang LH, Thanh TT. Design strategies to improve self-feeding device - FeedBot for Parkinson patients. In: International Conference on System Science and Engineering (ICSSE). Ho Chi Mihn City, Vietnam: IEEE; 2017. p. 765.
20. **Pulliam CL,** Heldman DA, Brokaw EB, Mera TO, Mari ZK, Burack MA. Continuous assessment of levodopa response in Parkinson's disease using wearable motion sensors. IEEE Trans Biomed Eng. 2018 Jan 1;65(1):159–64.
21. **Synnott J,** Chen L, Nugent C, Moore G. WiiPD – An Approach for the Objective Home Assessment of Parkinson's Disease. In: 33rd Annual International Conference of the IEEE EMBS. Boston, USA: IEEE; 2011.
22. **Ho MY,** Kuo MC, Chen CS, Wu RM, Chuang CC, Shih CS, et al. Pathological Gait Analysis With an Open-Source Cloud-Enabled Platform Empowered by Semi-Supervised Learning-PathoOpenGait. IEEE J Biomed Heal Informatics. 2024 Feb 1;28(2):1066–77.
23. **Rigas GA,** Tzallas AT, Baga DA, Exarchos TP, Katsis CD, Chaloglou DA, et al. PERFORM: First steps in the assessment of patient motion status and support to treatment changes. In: Proceedings of the 9th International Conference on Information Technology and Applications in Biomedicine, ITAB 2009. Larnaca, Cyprus: IEEE; 2009. p. 5–7.

24. **Madani K,** Lohi M, Lohi A. A decision support service platform for neurodegenerative disease patients. In: 6th International Conference on Networking and Services, ICNS 2010, Includes LMPCNA 2010; INTENSIVE 2010. Cancun, Mexico: IEEE; 2010. p. 188–91.
25. **Megalingam RK,** Pocklassey G, Jayakrishnan V, Mourya G, Thulasi A. Smartphone Based Continuous Monitoring Systemfor Home-bound Elders and Patients. In: International Conference on Communications and Signal Processing (ICCSP), 2014 3-5 April 2014, Melmaruvathur ; proceedings. India: IEEE; 2014.
26. **Ryder J,** Longstaff B, Reddy S, Estrin D. Ambulation: A tool for monitoring mobility patterns over time using mobile phones. In: Proceedings - 12th IEEE International Conference on Computational Science and Engineering, CSE 2009. Vancouver, BC, Canada: IEEE; 2009. p. 927–31.
27. **Patel S,** Chen B, Buckley T, Rednic R, Mcclure D, Tarsy D, et al. Home Monitoring of Patients with Parkinson's Disease via WearableTechnology and a Web-based Application. In: Annual international conference of the IEEE Engineering in Medicine and Biology Society (EMBC), 2010 Buenos Aires, Argentina, Aug 31, 2010 - Sept 4, 2010. Buenos Aires: IEEE; 2010.
28. **Chen B,** Buckley T, Rednic R, Patel S, Bonato P, Welsh M. MercuryLive: A Web-enhanced Platform for Long-term HighFidelity Motion Analysis. In: 2010 7th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON). Boston, MA, USA: IEEE; 2010. p. 123–6.
29. **Patel S,** Chen B, Mancinelli C, Paganoni S, Shih L, Welsh M, et al. Longitudinal Monitoring of Patients with Parkinson's Disease via Wearable Sensor Technology in the Home Setting. In: 33rd Annual International Conference of the IEEE EMBS. Boston, Massachusetts USA,: IEEE; 2011.
30. **Zhang Y,** Markovic S, Sapir I, Wagenaar RC, Little TDC. Continuous functional activity monitoring based on wearable tri-axial accelerometer and gyroscope. In: 2011 5th International Conference on Pervasive Computing Technologies for Healthcare and Workshops, PervasiveHealth 2011. Dublin, Ireland: IEEE; 2011. p. 370–3.
31. **Gatsios D,** Rigas G, Konitsiotis S. Design of a clinical decision support system powered by mhealth for the management of Parkinson's disease. In: 6th South-East Europe Design Automation, Computer Engineering, Computer Networks and Social Media Conference, SEEDA-CECNSM 2021. Preveza, Greece: IEEE; 2021.
32. **Fei H,** Ur-Rehman M. A Wearable Health Monitoring System. In: 2020 International Conference on UK-China Emerging Technologies (UCET) [Internet]. Glasgow, UK: IEEE; 2020. Available from: https://www.winbond.com/resource-files/w25q16dv
33. **Pierleoni P,** Belli A, Bazgir O, Maurizi L, Paniccia M, Palma L. A Smart Inertial System for 24h Monitoring and Classification of Tremor and Freezing of Gait in Parkinson's Disease. IEEE Sens J. 2019 Dec 1;19(23):11612–23.
34. **Jusufi I,** Nyholm D, Memedi M. Visualization of spiral drawing data of patients with Parkinson's disease. In: Proceedings of the International Conference on Information Visualisation. Institute of Electrical and Electronics Engineers Inc.; 2014. p. 346–50.
35. **Santos D,** Neto M, Lemos M, Silva V, Federal W, Junior V. Wearable System for Early Identification of Parkinson's Disease Symptoms Through the Evaluation of the Gait Training. In: Proceedings 2019 IEEE 9th International Conference on Consumer Electronics (ICCE-Berlin). Berlin, Germany: IEEE; 2019.
36. **Polychronidou E,** Kalamaras I, Votis K, Tzovaras D. HealthVision: An interactive web based platform for healthcare data analysis and visualisation. In: 2019 IEEE Conference on Computational Intelligence in Bioinformatics and Computational Biology (CIBCB) : 9-11 July 2019, Certosa di Pontignano, Siena, Italy. Siena, Italy : IEEE; 2019.
37. **Solachidis V,** Moreno JR, Hernandez-Penaloza G, Vretos N, Alvarez F, Daras P. TeNDER: Towards efficient Health Systems through e-Health platforms employing multimodal monitoring. In: Proceedings - 2021 IEEE/ACM Conference on Connected Health: Applications, Systems and Engineering Technologies, CHASE 2021. Washington, DC, USA: Institute of Electrical and Electronics Engineers Inc.; 2021. p. 185–92.
38. **Belmonte-Hernández A,** Hernández-Peñaloza G, Álvarez F, Theodoridis T, Solachidis V, Vretos N, et al. A Novel Framework for Physical Therapy Rehabilitation Monitoring and Assessment in Parkinson Disease Patients using Depth Information. In: ACM International Conference Proceeding Series. Association for Computing Machinery; 2019. p. 535–9.
39. **Kumar NK,** Viknesh CK, Rajamani AS, Wishma D, Vipraja V, Seetharaman R. Automatic Grading System of Parkinson's Disease using Smart App for Remote Monitoring System. In: 7th International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud), I-SMAC 2023 - Proceedings. Institute of Electrical and Electronics Engineers Inc.; 2023. p. 815–24.
40. **Fadhlannisa NF,** Basari B. Design of Wireless Electromyography (EMG) Monitoring System for Muscle Activity Detection on Parkinson Disease. In: Proceeding - ICoSTA 2020: 2020 International Conference on Smart Technology and Applications: Empowering Industrial IoT by Implementing Green Technology for Sustainable Development. Surabaya, Indonesia: IEEE; 2020.
41. **Niazmand K,** Tonn K, Kalaras A, Kammermeier S, Boetzel K, Mehrkens JH, et al. A measurement device for motion analysis of patients with Parkinson's disease using sensor based smart clothes. In: 2011 5th International Conference on Pervasive Computing Technologies for Healthcare and Workshops, PervasiveHealth 2011. Dublin, Ireland: IEEE; 2011. p. 9–16.
42. **Bernardini S,** Cianfrocca C, Maioni M, Pennacchini M, Tartaglini D, Vollero L. A Mobile App for the Remote Monitoring and Assistance of Patients with Parkinson's Disease and their Caregivers. In: 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), 2909-2912. IEEE; 2018.
43. **Gugliandolo G,** Campobello G, Capra PP, Marino S, Bramanti A, Di Lorenzo G, et al. A Movement-Tremors Recorder for Patients of Neurodegenerative Diseases. IEEE Trans Instrum Meas. 2019 May 1;68(5):1451–7.

44. **Wagner R,** Ganz A. PAGAS: Portable and Accurate Gait Analysis System. In: 34th Annual International Conference of the IEEE EMBS. San Diego, California USA,: IEEE; 2012.
45. **Cunha J,** Rocha A, Choupina H, Fernandes J, Rosas M, Vaz R, et al. A Novel Portable, Low-Cost Kinect Based System for Motion Analysis in Neurological Diseases. In: Annu Int Conf IEEE Eng Med Biol Soc. Orlando: IEEE; 2016.
46. **Lin W-Y,** Chou W-Z, Wu W-S, Lee M-Y. An Accelerometer-based Festinating Gait Detection Algorithm and Its Application to Parkinson's Disease Development. In: 2016 IEEE International Conference on Systems, Man, and Cybernetics. Budapest, Hungary: IEEE; 2016.
47. **Bourazeri A,** Stumpf S. Co-designing smart home technology with people with dementia or Parkinson's disease. In: ACM International Conference Proceeding Series. Association for Computing Machinery; 2018. p. 609–21.
48. **Zhang H,** Guo G, Song C, Xu C, Cheung K, Alexis J, et al. PDLens: Smartphone knows drug effectiveness among Parkinson's via daily-life activity fusion. In: Proceedings of the Annual International Conference on Mobile Computing and Networking, MOBICOM. Association for Computing Machinery; 2020. p. 150–63.
49. **Lennon T,** Bernier T, Tamayo D, Goldberg C, Mankodiya K. Multi-sensory system for monitoring dyskinesia in movement disorders. In: NEBEC : 2015 41st annual Northeast Biomedical Engineering Conference : 17-19 April 2015. Troy, NY, USA: IEEE; 2015.
50. **Pereira C,** Macedo P, Madeira RN. Mobile integrated assistance to empower people coping with Parkinson's disease. In: ASSETS 2015 - Proceedings of the 17th International ACM SIGACCESS Conference on Computers and Accessibility. Association for Computing Machinery, Inc; 2015. p. 409–10.
51. **Branco D,** Ferreira J, Bouça R, Guerreiro T. Designing free-living reports for Parkinson's disease. In: Conference on Human Factors in Computing Systems - Proceedings. Glasgow, Scotland, UK: Association for Computing Machinery; 2019.
52. **Dubey H,** Goldberg JC, Abtahi M, Mahler L, Mankodiya K. EchoWear: Smartwatch technology for voice and speech treatments of patients with Parkinson's disease. In: Proceedings - Wireless Health 2015, WH 2015. Bethesda, USA: Association for Computing Machinery, Inc; 2015.
53. **McNaney R,** Morgan C, Kulkarni P, Vega J, Heidarivincheh F, McConville R, et al. Exploring Perceptions of Cross-Sectoral Data Sharing with People with Parkinson's. In: Conference on Human Factors in Computing Systems - Proceedings. Association for Computing Machinery; 2022.
54. **McNaney R,** Poliakov I, Vines J, Balaam M, Zhang P, Olivier P. LApp: A speech loudness application for people with Parkinson's on google glass. In: Conference on Human Factors in Computing Systems - Proceedings. Association for Computing Machinery; 2015. p. 497–500.
55. **Chuang Y-T,** Melliar-Smith PM, Moser LE. A patient-centered health monitoring system. In: Wireless Health 2010. ACM; 2010. p. 232.
56. **Zhu W,** Anderson B, Zhu S, Wang Y. A computer vision-based system for stride length estimation using a mobile phone camera. In: ASSETS 2016 - Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility. Association for Computing Machinery, Inc; 2016. p. 121–30.
57. **McNaney R,** Othman M, Richardson D, Dunphy P, Amaral T, Miller N, et al. Speeching: Mobile crowdsourced speech assessment to support self-monitoring and management for people with Parkinson's. In: Conference on Human Factors in Computing Systems - Proceedings. San Jose, USA: Association for Computing Machinery; 2016. p. 4464–76.
58. **Lipsmeier F,** Taylor KI, Kilchenmann T, Wolf D, Scotland A, Schjodt-Eriksen J, et al. Evaluation of smartphone-based testing to generate exploratory outcome measures in a phase 1 Parkinson's disease clinical trial. Mov Disord. 2018 Aug 1;33(8):1287–97.
59. **De Barros AC,** Cevada J, Bayés À, Alcaine S, Mestre B. User-centred design of a mobile self-management solution for parkinson's disease. In: Proceedings of the 12th International Conference on Mobile and Ubiquitous Multimedia, MUM 2013. 2013.
60. **Isaacson SH,** Boroojerdi B, Waln O, McGraw M, Kreitzman DL, Klos K, et al. Effect of using a wearable device on clinical decision-making and motor symptoms in patients with Parkinson's disease starting transdermal rotigotine patch: A pilot study. Park Relat Disord. 2019 Jul 1;64:132–7.
61. **Belmonte-Hernández A,** Semerci YC, Proença JP, Romera-Giner S. PROCare4Life: An integrated care platform to improve the quality of life of Parkinson's and Alzheimer's patients. In: ACM International Conference Proceeding Series. Association for Computing Machinery; 2022. p. 358–64.
62. **Djurić-Jovičić M,** Petrović I, Ječmenica-Lukić M, Radovanović S, Dragašević-Mišković N, Belić M, et al. Finger tapping analysis in patients with Parkinson's disease and atypical parkinsonism. J Clin Neurosci. 2016;30:49–55.
63. **Schlachetzki JCM,** Barth J, Marxreiter F, Gossler J, Kohl Z, Reinfelder S, et al. Wearable sensors objectively measure gait parameters in Parkinson's disease. PLoS One. 2017;12(10):1–18.
64. **Lawrence BJ,** Gasson N, Kane R, Bucks RS, Loftus AM. Activities of daily living, depression, and quality of life in Parkinson's disease. PLoS One. 2014;9(7):1–5.
65. **Kim Y,** Heo E, Lee H, Ji S, Choi J, Kim JW, et al. Prescribing 10,000 steps like aspirin: Designing a novel interface for data-driven medical consultation. Conf Hum Factors Comput Syst - Proc. 2017;2017-May:5787–99.
66. **Stadler JG,** Donlon K, Siewert JD, Franken T, Lewis NE. Improving the Efficiency and Ease of Healthcare Analysis Through Use of Data Visualization Dashboards. Big Data. 2016;4(2):129–35.
67. **Wannheden C,** Revenäs Å. How people with parkinson's disease and health care professionals wish to partner in care using ehealth: Co-design study. J Med Internet Res. 2020;22(9).
68. **Gagnon MP,** Ngangue P, Payne-Gagnon J, Desmartis M. m-Health adoption by healthcare professionals: A systematic review. J Am Med Informatics Assoc. 2016;23(1):212–20.