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Review article

Smartphone applications for Movement Disorders: Towards collaboration and re-use

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A R T I C L E I N F O

Keywords:
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A B S T R A C T

Background: Numerous smartphone and tablet applications (apps) are available to monitor movement disorders, but an overview of their purpose and stage of development is missing.
Objectives: To systematically review published literature and classify smartphone and tablet apps with objective measurement capabilities for the diagnosis, monitoring, assessment, or treatment of movement disorders.
Methods: We systematically searched for publications covering smartphone or tablet apps to monitor movement disorders until November 22nd' 2023. We reviewed the target population, measured domains, purpose, and technology readiness level (TRL) of the proposed app and checked their availability in common app stores.
Results: We identified 113 apps. Most apps were developed for Parkinson's disease specifically (n = 82; 73%) or for movement disorders in general (n = 17; 15%). Apps were either designed to momentarily assess symptoms (n = 65; 58%), support treatment (n = 22; 19%), aid in diagnosis (n = 16; 14%), or passively track symptoms (n = 11; 10%). Commonly assessed domains across movement disorders included fine motor skills (n = 34; 30%), gait (n = 36; 32%), and tremor (n = 32; 28%) for the motor domain and cognition (n = 16; 14%) for the non-motor domain. Twenty-six (23%) apps were proof-of-concepts (TRL 1–3), while most apps were tested in a controlled setting (TRL 4–6; n = 63; 56%). Twenty-four apps were tested in their target setting (TRL 7–9) of which 10 were accessible in common app stores or as Android Package.
Conclusions: The development of apps strongly gravitates towards Parkinson's disease and a selection of motor symptoms. Collaboration, re-use and further development of existing apps is encouraged to avoid reinventions of the wheel.

1. Introduction

Advances in digital technology, including tablet and smartphone applications (apps), offer a possibility to overcome the limitations of in-clinic neurological assessments. The diagnosis and treatment by healthcare professionals is limited by in-clinic, momentary assessments of patients' functioning. However, these assessments do not objectively capture the patient's functioning in daily life or symptoms variability [1]. Digital technologies provide an opportunity to monitor a wide range of symptoms actively and passively, both in the clinic and in daily life [2,3], to aid in the treatment or diagnosis of movement disorders. Digital measures are sensitive to longitudinal change in people with ataxia [4] and Parkinson's disease [5]. Moreover, a digital outcome measure for people with essential tremor seems responsive to medication and more sensitive than a clinical rating scale [6]. Measuring large populations is now feasible because off-the-shelf smartphones contain several built-in sensors such as a gyroscope, accelerometer, and magnetometer. Most people own a smartphone, rendering it a suitable device also for rural

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and coastal communities where people live further away from healthcare institutions. Although tablets lack these sensors, they can monitor or aid in treatment by facilitating touchscreen-based tasks, recording speech, and facilitating video-based tasks [7–9].

However, a clear overview of the purpose and stage of development of apps across movement disorders is needed to facilitate implementation of apps in clinical practice and prevent unnecessary duplication from multiple research groups across and within conditions. To date, reviews on smartphone apps are limited to specific movement disorders [10–12], appeared more than five years ago [12], or lack a systematic search [13]. Given the rapid technological developments in the field, a comprehensive update is needed.

To this end, we here systematically review and classify smartphone and tablet apps used to momentarily assess symptoms, support treatment, aid in diagnosis, or passively track symptoms of movement disorders. Our review targets a wide range of movement disorders to stimulate the transfer of findings from one movement disorder to another. We systematically searched the literature and provide a scoping review of the apps that are ready for use. Furthermore, we propose future directions for app development in the field of movement disorders.

2. Methods

2.1. Literature search

We conducted a literature search onNovember 22nd, 2023 using PubMed, Web of Science, Embase and Cochrane. Keywords included “mobile applications”, “tablet” and “smartphone” and were combined with keywords covering all primary movement disorders such as “movement disorders", “ataxia” and “tremor” and alike. The full search strategy can be found in Supplement 1.

2.2. Eligibility criteria

We included original studies meeting all of the following inclusion criteria: 1) studies involving a smartphone or tablet app, 2) the app focuses on objective monitoring, 3) the target population involves individuals with a neurological movement disorder and 4) the article is accessible and published in English. We included the following neurological movement disorders or symptoms: Parkinson’s disease, ataxia, essential tremor, dystonia, Huntington’s disease, multiple system atrophy, myoclonus, progressive supranuclear palsy, Rett syndrome, secondary parkinsonisms, spasticity, tardive dyskinesia, Tourette syndrome and Wilson’s disease. Reasons to exclude papers are given in supplement 2.

2.3. Article selection process

One reviewer (IHJW) performed the first pass, in which articles were selected based on title and abstract. IHJW screened the reference lists of reviews that were selected in the first pass. Articles identified through reference lists were considered for inclusion based on their title. For the second pass, IHJW and a second reviewer (SS or RB) examined the full text for compliance with the eligibility criteria. Discrepancies between the judgement of the reviewers (i.e., inclusion or exclusion), were resolved in a consensus meeting with all three reviewers.

2.4. Data extraction

From the included articles, we extracted the study design characteristics such as type of study (i.e., proof of concept, validation study; see Supplement 3) and study population as well as the name and characteristics of the apps. We categorized the apps obtained from the publications according to their purpose as follows: 1) aid in diagnosis, 2) momentarily assess symptoms, 3) passively track symptoms and 4) support treatment. We determined the technology readiness level (TRL) [14] of all included apps and classified them in three groups: TRL 1–3 covers app design and proof-of-concept studies, TRL 4–6 covers validation in lab-based and target settings, and TRL 7–9 covers a (fully) functional deployment in target settings. Moreover, we checked the availability of apps in the Google Play Store and Apple App Store for Europe and the United States, and searched for the availability of an Android package kit (APK). Other extracted article and app characteristics are listed in Supplement 3. For each disorder, we selected the most advanced apps based on their technology readiness level (TRL 4–6 or 7–9) and availability (available in the Google Play Store, Apple App Store or as APK). If more than four apps were selected for one movement disorder, we selected the four apps with the highest number of people included in the studies.

3. Results

3.1. Apps for movement disorders

We screened 2864 articles and included 150 in the review, which in total describe 113 unique apps (Supplement 2; Supplement 4). The 113 unique apps were either available for smartphone (n = 82; 73%), tablet (n = 20; 18%) or both (n = 11; 10%). The apps were developed for Parkinson’s disease (n = 82), ataxia (n = 5), Huntington’s disease (n = 5), cerebral palsy (n = 4), orthostatic tremor (n = 4), essential tremor (n = 3), or primary dystonia[a] (n = 1). Some apps were not developed for a specific movement disorder (n = 17; Table 1). Some apps were developed for multiple movement disorders, hence the sum of the number of apps exceeds the total number of apps (n = 113, Table 1). Out of the 113 apps, 65 (58%) were intended to be used at home, 13 (12%) in the clinic, 13 (12%) both at home and in the clinic, and for 23 (20%) this was not reported. Across all apps for which a target setting was known (91), 30 apps (33%) were not tested in their intended target setting.

3.2. Purpose of the apps

We identified 65 apps (58%) that had the purpose to momentarily assess symptoms (Fig. 1). These apps provide digitized versions of clinical tests such as finger tapping or spiral drawing tasks [15,16], short walking and balance tests [17], or tremor assessments [18]. The second most common purpose was to support treatment (n = 22; 19%), for example by using music and cues to train gait [19], adjust medication intake based on symptom tracking [20], or offer guided breathing exercises [21]. Supporting the diagnostic process was the third most common app purpose (n = 16; 14%), for instance by measuring tremor in the leg to diagnose orthostatic tremor [22], recording voice data to detect early Parkinson [23], or assessing dystonia severity through a tapping task [24]. Finally, some apps primarily focus on passively tracking symptoms (n = 11; 10%), for example by analyzing changes in voice quality via phone call recordings [25] or tracking functional mobility and outdoor position [26].

3.3. Domains

Frequently assessed symptoms for all movement disorders included motor symptoms such as gait, tremor, fine motor skills, or balance (Table 2). Cognition was a commonly assessed non-motor symptom across several movement disorders. Lastly, several apps included additional ePRO’s (electronic patient reported outcomes) and measures of physical activity.

[a] The term primary dystonia was adopted from the corresponding article.

Table 1
Number of apps per movement disorder.

	Parkinson	Various MD	Ataxia	Huntington	Cerebral palsy	Orthostatic tremor	Essential tremor	Primary dystonia	Total
Number of apps:	82	17	5	5	4	4	3	1	113
Apps TRL 7–9:	23%	24%	20%	20%	25%	75%	33%	0%	21%
Apps available:	24%	29%	40%	40%	25%	25%	0%	0%	23%

TRL = Technology Readiness Level. App was defined as available if available in Google Play Store or Apple App Store for Europe or the United States or available as Android package kit. The term primary dystonia was adopted from the corresponding article.

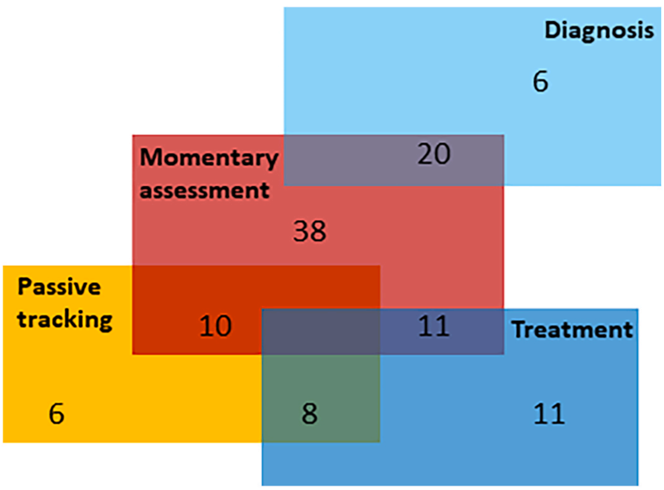

Fig. 1. Venn diagram of app purposes.

3.4. Tools

Almost half of the apps (47; 42%) did not require assistive tools to operate the app, for example apps that assessed fine motor skills, cognition and speech. For the apps that required an assistive tool, the most often reported were a strap or a similar tool to attach the smartphone to the body (n = 24; 21%) to assess gait, balance and tremor, or inertial measurement units (n = 14; 12%) to assess (freezing of) gait, and smartwatches (n = 13; 12%) to assess tremor, physical activity, and sleep to provide sensor input to the app.

3.5. Technological readiness levels and availability

Overall, 26 apps (23%) are in the lowest TRL (1–3), meaning that these apps have only gone through an experimental proof of concept. Most apps have been validated in a lab-based setting or purpose-relevant environment and are therefore in TRL 4–6 (n = 63; 56%). Twenty-four apps (21%) have been evaluated in an operational environment or are ready for deployment (TRL 7–9). For only one app, we found publications across all three TRL stages and for nine apps we found publications across two TRL stages (Fig. 2). A comparable distribution was seen across apps that include ePROs in addition to an objective measure (6% in TRL 1–3; 59% in TRL 4–6; 35% in TRL 7–9). Four (17%) of the apps in TRL 1–3 are available in common app stores or as Android Package (apk). For TRL 4–6 and 7–9 these numbers were 13 (22%) and 10 apps (40%), respectively. Out of all apps, 11% (n = 12) were developed for both Android and iOS. Only seven apps (6%) were used in a clinical trial of which six were in TRL 7–9 [19,27–33] and one in TRL 4–6 [17,34,35]. The two most targeted symptoms in these seven apps were gait and fine motor skills, which were assessed in four and three of the apps, respectively.

3.6. The most advanced apps per movement disorder

We identified the most advanced apps across all movement disorders based on their TRL, availability, and number of people that were measured with the app (Table 3). Most apps did not report a validation

Table 2
Number of apps measuring various symptom domains categorized per movement disorder.

Domains measured	Parkinson	Various MD	Ataxia	Huntington	Cerebral palsy	Orthostatic tremor	Essential tremor	Primary dystonia	Total
Motor symptoms									
Gait	27	3	3	2	2	1			36
FOG	7								7
Balance	14	1	3	2		1			19
Tremor	21	11		2		3	3		32
Fine motor skills	26	4	3	1	1			1	34
Dyskinesia	4	1							5
Chorea				2					2
Bradykinesia	10								10
Hypokinesia	1								1
Akinesia	1								1
Rigidity		1							1
Speech	13	1	1	2					16
Falls	1								1
Non-motor symptoms									
Cognition	14	2		3					16
Sleep	3			1					4
Pain					1				1
Other									
ePRO	14	1	1	2					17
Physical activity	13			2					14
Medication	4								4
Lifespace	1								1

MD = movement disorders; FOG = Freezing of Gait; ePRO = electronic patient reported outcome. The term primary dystonia was adopted from the corresponding article.

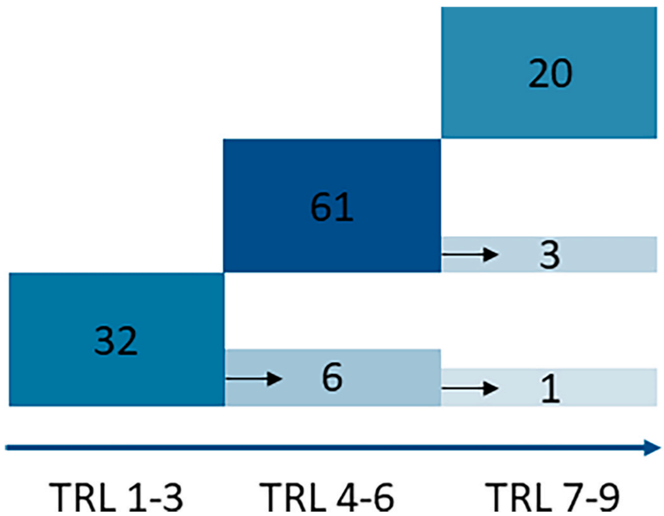

Fig. 2. Overview of applications across Technology Readiness Levels (TRL).

against a sensor system, but rather reported validation against existing clinical rating scales and/or by the ability to differentiate between healthy participants and patients [28,36]. The apps that reported a validation against an external system were App-Coo-Test (postural sway with a footboard) [37], iSeismometer, StudyMyTremor, LiftPulse (EMG recordings) [18,38] and Mon4t Clinic (motion capture cameras, a pressure mat and wearable sensor) [39]. For three of the 11 most advanced apps the papers described how data collected with the app was secured (HopkinsPD [40], Roche PD mobile application [28–30], and Mon4t Clinic [39,41]. Data collection of the HopkinsPD app [40] was described in most detail and was also the only study that mentioned to adhere to guidelines (Health Insurance Portability and Accountability Act (HIPAA)). None of the 11 apps were certified as medical device. We briefly describe these 11 apps and their intended context of use below.

For ataxia, the most advanced apps include the App-Coo-Test [36,37] and SARAhome [42]. Both apps are available for Apple and Android devices and available in the Apple App Store and Google Play Store. The App-Coo-Test [36,37] uses smartphone sensors to determine body sway as a measure of balance capacity and uses the smartphone touchscreen to measure fine motor skills. These measures could be used by clinicians to (remotely) monitor patients at home, or by patients to improve their balance or fine motor skills. The App-Coo-Test was validated in cerebellar ataxia patients and healthy subjects in a controlled setting. The SARAhome [42] is a tablet app in which a trained rater scores ataxia severity based on video assessments at home. The SARAhome correlated highly (0.93) with the conventional SARA [43] in a lab-based validation with 50 ataxia patients. Furthermore, SARAhome recordings seem feasible in a home-based pilot with 12 ataxia patients. The four most advanced apps for Parkinson's disease were all in TRL 7–9: mPower [44–46], HopkinsPD [40,47], Roche PD Mobile application [28,29] and Mon4t Clinic [39,41,48]. These apps assess five or more affected domains of Parkinson's disease by collecting smartphone-based sensor data of patients while they perform self-guided tasks. Except for the Mon4t Clinic app, these apps also passively track symptoms. The mPower app [44] has already been used by over 10.000 people worldwide. Their digital outcome measure determined through home-based smartphone tasks, i.e. balance, finger tapping, gait, and voice, correlated with disease severity. The HopkinsPD app [47] has been designed to detect medication response, which in the future could assist in therapeutic decision making. In a clinical trial, the Roche PD mobile app [28] collected clinically meaningful digital biomarkers for Parkinson's

Table 3
Eleven most advanced apps for neurological movement disorders.

Name	TRL	Movement disorder(s)	Purpose	User	Domain(s)	Test setting	Target setting	Operating system	
								Android	iOS
App-Coo-Test	7–9	Ataxia	1. Momentary assessment	Clinicians	Balance, Fine motor skills	Clinic	Home	**Yes**	**Yes**
SARAhome	4–6	Ataxia	1. Momentary assessment	Clinicians	Balance, Fine motor skills, Gait & Speech	Clinic Home	Home	**Yes**	**Yes**
iSeismometer	7–9	MD	1. Momentary assessment 2. Diagnosis	Clinicians	Tremor	Clinic	Clinic	Yes*	**Yes**
StudyMyTremor	7–9	OT	1. Diagnosis 2. Momentary assessment	Clinicians	Tremor	Clinic	Clinic		**Yes**
BrightHearts	4–6	Cerebral palsy	1. Treatment	Patients	Pain	Home	Home		**Yes**
mPower	7–9	Parkinson	1. Momentary assessment 2. Passive tracking	Clinicians	Balance, Cognition, ePRO, Fine motor skills, Gait, PA, Speech & Tremor	Clinic Home	Home	**Yes**	**Yes**
HopkinsPD	7–9	Parkinson	1. Momentary assessment 2. Passive tracking	Clinicians	Balance, Cognition, Fine motor skills, Gait & Speech	Clinic Home	Home	Yes*	
Roche PD Mobile application	7–9	Parkinson Huntington	1. Momentary assessment 2. Passive tracking	Researchers	Balance, Cognition, ePRO, Fine motor skills, Gait, PA, Speech & Tremor	Clinic Home	Clinic Home	**Yes**	**Yes**
Mon4t Clinic	7–9	Parkinson MD	1. Momentary assessment 2. Diagnosis	Clinicians	Balance, Cognition, Fine motor skills, Gait & Tremor	Clinic Home	Clinic Home	**Yes**	**Yes**
Neural Impairment Test Suite	4–6	Huntington	1. Momentary assessment 2. Diagnosis	Clinicians	Cognition, ePRO, Tremor & Speech	Home	Home	Yes*	
Lift Pulse	7–9	ET OT MD	1. Momentary assessment 2. Diagnosis	Clinicians	Tremor	Clinic	Clinic	Yes*	Yes*

TRL = Technology Readiness Level; MD = movement disorders; OT = orthostatic tremor; ET = essential tremor; ePRO = electronic patient reported outcome; PA = physical activity; Yes = compatible with Android/Apple. Yes in bold is available in that Appstore. Marked with an asterisk is available as Android Package (apk). Mon4t Clinic app was formerly known as EncephaLog.

disease. The Mon4t Clinic app [41] was used as alternative for regular follow-up patient care during the COVID-19 pandemic in combination with telephone calls and could support remote follow-up of patients.

For tremor analysis, the apps iSeismometer [18], StudyMyTremor [18,38], and Lift Pulse [18,49] provided smartphone-based measurements in various movement disorders patients that appeared to serve as a reliable alternative for electromyography (EMG) tremor analysis. The smartphone was strapped to the tremulous limb in 22 movement disorders patients for data recording and provided an objective tremor frequency to support diagnosis and therapeutic decision making. In addition, StudyMyTremor [38] assessed orthostatic tremor and Lift Pulse [49] was able to measure head tremor. The Neural Impairment Test Suite [50] contains touchscreen-based tasks that can be performed on a smartphone or tablet. The app differentiated between healthy people and participants with Huntington's disease in a pilot study, showing it's potential to support the detection of motor abnormalities in Huntington's disease. In addition, the Roche PD mobile app [30], initially developed for Parkinson's disease, showed to be reliable and valid for remote monitoring of Huntington's disease symptoms as well. The outcome measures of the app were found to be related to clinical severity and disease stage. Finally, for cerebral palsy, the app Bright-Hearts [21] offers assisted relaxation training for chronic pain in children with cerebral palsy based on heartrate monitoring. The app provides relaxing chime sounds each time their heartrate drops, in combination with visual artwork on the smartphone screen. The app proved to be feasible for pain management in 10 children with cerebral palsy.

4. Discussion

We identified 113 unique apps to momentarily assess or passively track symptoms, aid in diagnostic processes, or support treatment of neurological movement disorders. The majority of these apps (n = 82, 73%) have been developed for Parkinson's disease and focus on measuring motor symptoms, although some apps (also) measure cognition, ePROs, and physical activity. Given the fact that the prevalence of Parkinson's disease is much higher than other movement disorders, this might not be surprising as this will also be reflected by a higher interest of academia and industry [51]. We selected the most advanced apps across movement disorders of which eight are closest to implementation (TRL 7–9). The apps that passively track symptoms focus on measuring balance and gait capacity, whilst apps for momentary assessment mainly center around fine motor skills, tremor, and speech. Subsequently, the objective information collected with these apps could support the diagnostic process.Notably, no apps designed to support treatment are in the final stage of development (TRL 7–9). The number of apps developed for movement disorders has increased considerably in recent years, although the coverage across the wide range of movement disorders remains incomplete. A review published in 2016 described 24 different smartphone apps relevant for Parkinson's disease [12]. In our review up until 2023, we found three times as many apps for Parkinson's disease (82; 61 smartphone apps). In contrast, we identified only 22 apps that targeted a specific movement disorder other than Parkinson's disease, showing limited development outside the domain of Parkinson's disease. There are specific gaps for atypical parkinsonisms and disorders involving myoclonus and tics. Despite the lower number of apps available for these movement disorders, the percentage of apps reaching TRL 7–9 or being available in app stores is almost comparable to that for Parkinson's disease.

To accelerate the development and quality of apps, we suggest to strengthen the collaboration and crosstalk between research groups and patients. Currently, several groups independently develop apps for specific movement disorders that measure the same symptom domains. For example, within Parkinson's disease, 27 apps track gait, 21 measure tremor, and 26 assess fine motor skills. Similarly, the apps that were developed for other movement disorders also target gait (9), tremor (11), and fine motor skills (8). Apps for these clusters of symptoms differ in their graphical design, test setting and population, but often rely on highly comparable smartphone or smartwatch sensors. The symptom domains represented in the apps for Parkinson's disease that overlap with other movement disorders can also be used in these conditions. However, to be fully comprehensive, the other symptoms that people which such a movement disorder experience, need to be added. Instead of reinventing the wheel within the silos of each movement disorder, we urge researchers and developers to combine efforts. For example, apps that measure cognition in people with Parkinson's and Huntington's disease could be (partly) transferred to measure cognition in ataxia. Furthermore, transparency of validation steps of technological components will allow translation to other applications. Thereby, we can increase development speed and create apps of higher quality that cover multiple symptom domains and are useful for multiple movement disorders. The percentage of apps that reaches the final stage of development, supported by research, needs to be increased to make the most out of the time, effort and money put into these projects. For a very small minority of apps, scientifically supported advancement through subsequent TRL blocks is available. Only 24 of the 113 (21%) apps in our review reached TRL 7–9, which may be for various reasons. First, research projects are often time-bound, and maintenance and ownership of an app after the project ends is costly. We therefore strongly advise researchers and clinicians to include strategies for post-study implementation, ownership, and maintenance in the research plan. One potential route to sustainable financing of apps is through reimbursement by government and insurance bodies. Some digital health apps in Germany became reimbursable through the statutory health insurance system with the adoption of the Digital Healthcare Act in 2019 [52]. Although this act encourages clinicians and patients to adopt digital technologies, the cost-effectiveness of this system, and of specific apps, needs to be proven. The second reason is a lack of consensus on the most appropriate approach for data capturing with smartphone applications in the clinic and at home. Clear guidelines and accessible reporting can accelerate app development by providing standardized task-based outcome measures relevant to the symptom domain of interest. Third, the needs of all involved parties, e.g., clinicians, patients, and caregivers, are sometimes too late taken into consideration in the development process [53]. The perspective of patients must be included from the start of development when the outcome domains of interest are identified. People with Parkinson's disease and clinicians sometimes agree on the domains to be assessed [54], while they might also prioritize these domains differently [55]. We advise to use the four-level framework presented by Manta et al. to determine the most meaningful outcome measures [56].

Despite the tremendous increase in the number of developed apps, only a small portion becomes available for end users. Only a quarter of the apps that we described were accessible in the app stores. On top of that, only 12% of apps is built for both the Android and Apple operating systems. To facilitate research and implementation in clinical practice, apps should be accessible by researchers, patients or clinicians. Importantly, some of the apps in very early development stages are already widely available, but without showing a standardized quality appraisal for validation. The roadmap published by the Movement Disorders Society Task Force on Technology [57] could serve as guideline for development and implementation and we therefore strongly advise to use this roadmap in the development process of smartphone and tablet apps. However, validity of the apps against gold standards, as suggested in the roadmap, could not be systematically evaluated by us due to the lack of published data on items such as accuracy, reliability, and measurements errors of the apps. As an illustration, we found that even for the 11 most advanced apps, only four apps were supported with a paper reporting validation against an already validated system. Furthermore, for apps in the highest TRL, the field is awaiting relevant publications on post-marketing surveillance. Such readily accessible post-marketing surveillance reports alongside quality appraisal could increase trust in the utility of apps in clinical practice and enable comparisons across apps. We found that even the most advanced apps were not certified as medical devices. A possible explanation for this might be the strict requirements, additional technical documentation, and extended submission procedures that ethical committees demand for conducting research with medical devices.

This review has several strengths. First, we performed an extensive systematic search covering the wide spectrum of movement disorders and rigorously selected articles against predefined inclusion criteria. Second, we categorized the apps according to the TRL and provide a list of apps that are closest to implementation in clinical practice. Our study also has some limitations. First, we excluded conference abstracts and we might have therefore missed the most recent app developments. Second, we deliberately chose not to include e-diaries in this review because we wanted to provide an overview of apps that provide an objective measure. We included apps that contain a patient reported outcome only if the primary purpose was objective monitoring. Third, we did not evaluate whether the apps complied with the General Data Protection Regulation [58]. Fourth, for the scope of our review, we classified the most advanced apps per movement disorders based on their TRL, availability, and number of people that were measured with the app. However, a different study objective will very likely lead to a different set of criteria, for example including cost-effectiveness and readiness for clinical uptake. Lastly, we only evaluated whether the 11 most advanced apps were formally certified as medical device.

5. Conclusion

This review provides clinicians, researchers, and patients an overview of the developed and available apps for movement disorders. Overall, we found many apps for neurological movement disorders, but most need further development and evaluation prior to implementation in clinical practice. The field gravitates towards Parkinson's disease and a selection of motor symptoms, leading to incomplete coverage of the disease and symptom spectra. We encourage collaboration within the field and re-use of existing apps to prevent reinventions of the wheel and premature termination of development efforts.

Author roles

Ilse H. J. Willemse: 1A, 1B, 1C, 2A, 2B, 2C, 3A, 3B
Sabine Schootemeijer: 1A, 1B, 1C, 2A, 2B, 2C, 3A, 3B
Robin van den Bergh: 1A, 1B, 1C, 2A, 2B, 2C, 3A, 3B
Bart P.C. van de Warrenburg: 1A, 2C, 3B
Jorik H. Nonnekes: 1A, 2C, 3B
Helen Dawes: 3B

Ethical compliance statement

We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this work is consistent with those guidelines. The authors confirm that the approval of an institutional review board was not required for this work.

Funding sources and conflict of interest

No specific funding was received for this work. The authors have no conflicts of interest to declare.

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CRediT authorship contribution statement

Ilse H.J. Willemse: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft. **Sabine Schootemeijer:** Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft. **Robin van den Bergh:** Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft. **Helen Dawes:** Writing – review & editing. **Jorik H. Nonnekes:** Conceptualization, Supervision, Writing – review & editing. **Bart P.C. van de Warrenburg:** Conceptualization, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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