Use of Wearables Among Multiple Sclerosis Patients and Healthcare Professionals: A Scoping Review

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Keywords: HCP perceptions, multiple sclerosis, patient perceptions, scoping review, wearable technology.

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Abstract

Introduction: Multiple sclerosis (MS) is an increasingly prevalent chronic, autoimmune, and inflammatory central nervous system illness, whose common symptoms undermine the quality of life of patients and their families. Recent technical breakthroughs potentially offer continuous, reliable, sensitive, and objective remote monitoring solutions for healthcare. Wearables can be useful for evaluating falls, fatigue, sedentary behavior, exercise, and sleep quality in people with MS (PwMS).

Objective: This scoping review of relevant literature explores studies investigating the perceptions of patients and healthcare professionals (HCPs) about the use of wearable technologies in the management of MS.

Methods: The Joanna Briggs Institute methodology for scoping reviews was used. The search strategy was applied to the databases, MEDLINE via Ovid, Embase, APA PsycInfo, and CINAHL. Further searches were performed in IEEE, Scopus, and Web of Science. The review considered studies reporting quantitative or qualitative data on perceptions and experiences of PwMS and HCPs concerning wearables' usability, satisfaction, barriers, and facilitators.

Results: 10 studies were included in this review. Wearables' usefulness and accessibility, ease of use, awareness, and motivational tool potential were patient-perceived facilitators of use. Barriers related to anxiety and frustration, complexity, and the design of wearables. Perceived usefulness and system requirements are identified as facilitators of using wearables by HCPs, while data security concerns and fears of increased workload and limited effectiveness in the care plan are identified as barriers to use wearables.

Conclusions: This review contributes to our understanding of the benefits of wearable technologies in MS by exploring perceptions of both PwMS and HCPs. The scoping review provided a broad overview of facilitators and barriers to wearable use in MS. There is a need for further studies underlined with sound theoretical frameworks to provide a robust evidence-base for the optimal use of wearables to empower healthcare users and providers.

Keywords: HCP perceptions, multiple sclerosis, patient perceptions, scoping review, wearable technologies.

1. Introduction

Multiple Sclerosis (MS) is a chronic autoimmune and inflammatory central nervous system (CNS) condition [1]. The prevalence of MS has increased worldwide since 2013, with high treatment costs [2]. In the USA, the average costs per-person are estimated to be USD 65,612 for medical costs, and USD 17,407 for indirect costs [3]. While life expectancy has increased among people with MS (PwMS), the survival rate is still lower than expected compared to the general population (the median survival from birth was 75.9 years in the MS population and 83.4 years in the matched population) [4]. While the disease can affect people at any age, it is mostly diagnosed among those aged 20-40 years old [5]. Further research is needed to promote and improve the long-term self-management of the condition.

Technological advancements in recent decades can potentially offer feasible solutions to provide accurate, sensitive, and objective continuous remote monitoring in healthcare [6]. Wearable technologies ('wearables') can have the appearance of a watch, eyeglasses, clothing, contact lenses, shoes, or a piece of jewellery [7]. Lu et al. reviewed the current application of wearables and found four categories of wearable health device application, which are health and safety monitoring, management of chronic diseases, disease diagnosis and treatment and rehabilitation [8]. The information produced by wearable sensors is physiologically significant and meaningful, according to a study examining its utility, and it is expected to be essential for managing health in the future [9]. According to Sparaco et al. [10], motion wearable devices can be helpful for assessing falls, fatigue, sedentary behaviour, exercise, and sleep quality in PwMS.

Wearable are gaining popularity for everyday activities and are now routinely applied in managing long-term conditions like diabetes [11]. They also show promise in neurological disease management, for example in Parkinson's disease and epilepsy [12]. The potential use among PwMS has been under-explored until recently, despite the promising potential they could offer this patient group [11]. There is a need to understand how wearables and other lifestyle-supporting tools can be used by MS patients in a manner that is acceptable to them and healthcare professionals (HCPs).

While the perceptions of both patients and healthcare providers (HCPs) regarding the potential use of wearables in MS treatment and self-management have not been explored in depth, a qualitative study by Ozanne et al. investigated this topic [12]. It is noteworthy that the study by Ozanne et al. focused on 25 patients with Parkinson's disease or epilepsy and 15 HCPs, limiting the broader context of wearable technology in MS treatment. This study demonstrated that the benefits of wearing the sensors were outweighed by any potential inconvenience [12].The same study concluded that user groups including patients, HCPs and researchers should be involved in the co-design and implementation of wearable technologies in the care of patients with neurological conditions.

This scoping review identifies and analyzes knowledge gaps, records the types of available evidence in using wearables in MS, and explores the perceptions of PwMS and HCPs. Scoping reviews can help identify characteristics and concepts identified by existing studies, making this an appropriate method to address the review question [13]. Since research in this field is in its infancy, this scoping review explores the value of wearables in MS as perceived by patients and HCPs, investigating facilitators and barriers to their effective use in clinical practice.

2. Methods

This review was conducted in accordance with the Joanna Briggs Institute (JBI) Methodology for Scoping Reviews [14], during the period Aug 2022-Jan 2023.

2.1. Search strategy

The search strategy aimed to locate both published and unpublished studies. An initial limited search of MEDLINE, CINAHL, the Cochrane Database of Systematic Reviews, Cochrane

Library, and JBI Evidence Synthesis was undertaken to identify articles on the topic. The text words contained in the titles and abstracts of relevant articles, and the index terms used to describe the articles were used to develop a full search strategy for MEDLINE via Ovid, Embase, APA PsycInfo, and CINAHL (see Appendix). Sources of further literature were searched include IEEE, Scopus, and Web of Science. The reference lists of all included sources of evidence were screened to identify additional studies.

2.2. Selection criteria

This review adopts the PCC framework, which stands for Population/ participants, Concept, and Context, as recommended by the JBI, to identify the main concepts in the review question, as explained below [14]. Table 1 shows the eligibility criteria including types of participants, concept, context, and types of sources.

2.3. Study selection

After the search, all citations from all databases were transferred into EndNote X9 /2018 (Clarivate Analytics, PA, USA), and duplicates were removed using the same software. Titles and abstracts were screened for review inclusion and exclusion by one of the authors (SA), based on the agreed eligibility criteria. These were verified by the other two authors (ST and HW). SA conducted the first data extraction for full-text papers. Subsequently, all authors independently analyzed the retrieved data to achieve consensus on the final table. In case of disagreement consensus reached through discussion. The remaining papers were read in full-text version. Selected citations' complete texts were examined for inclusion criteria. The scoping review presented the search and study inclusion results in a Preferred Reporting Items for Systematic Reviews and Meta-analyses Extension for Scoping Review (PRISMA-ScR) flow diagram [15] (Figure 1).

2.4. Data extraction

Data were extracted from papers included in the scoping review, adopting the data extraction tool suggested by JBI [14]. The data extraction tool included specific details about the authors, research origin, aim, participants, study methods, intervention (if applicable), and key findings.

3. Results

3.1. Search results

The PRISMA flowchart was adopted to show the process of identifying sources of evidence (Figure 1) [16]. The search yielded 605 studies, and two further studies were identified via searching the reference lists of the initially retrieved studies. 558 records were retrieved after duplicates were removed, of which 510 records were excluded as irrelevant after screening titles and abstracts relative to the inclusion and exclusion criteria. Reasons for exclusion included the following: non-English language (n = 5) , not being full research papers (e.g., protocols and conference abstracts (n = 54), different objectives (n = 170), not including PwMS (n = 53), and not including wearables (n = 231). Forty-eight studies were eligible for full-text screening, of which 38 were subsequently excluded due to not being full research papers, having different objectives, and not including wearables. 10 studies were ultimately included in this review, as summarized in Table 2.

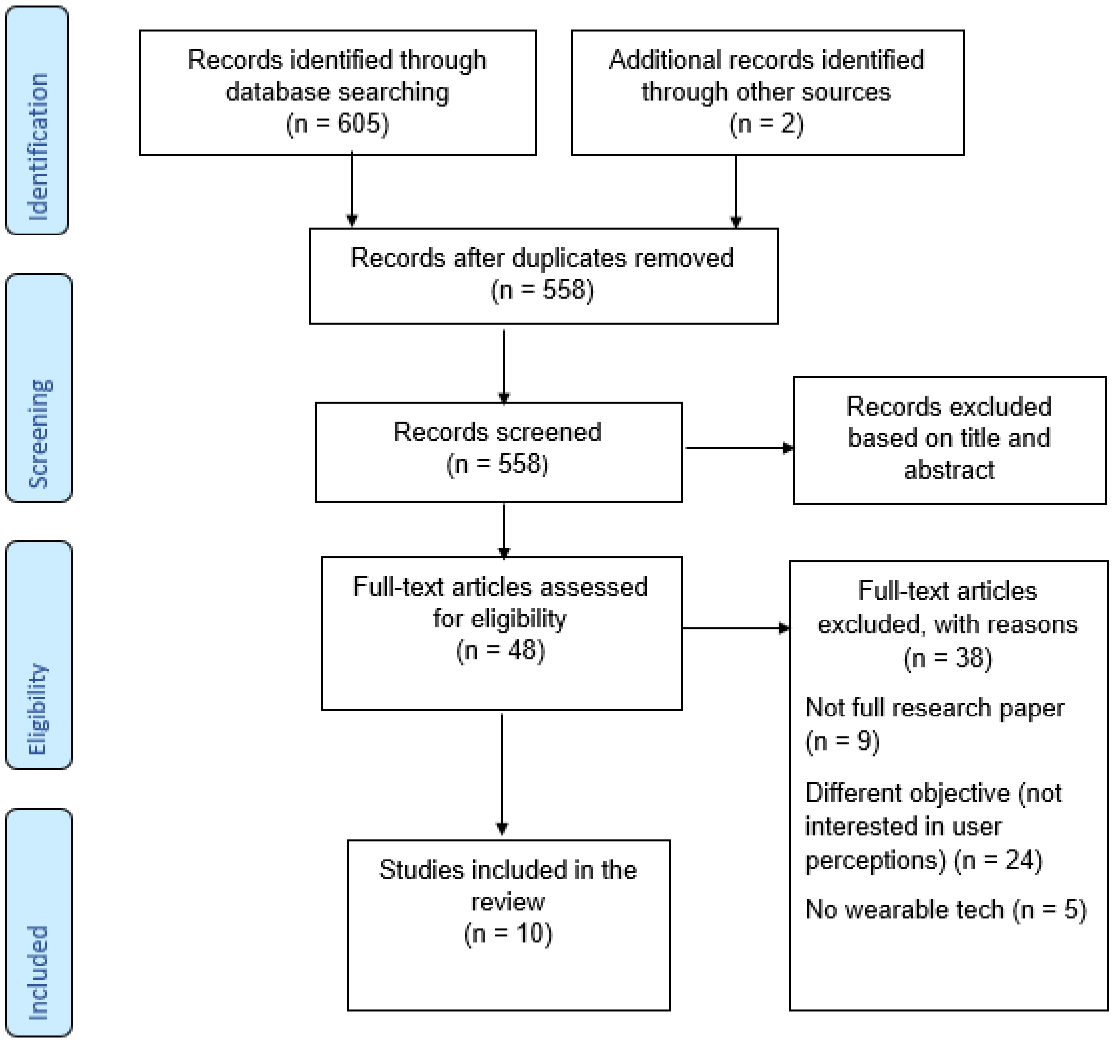

Figure 1: PRISMA flow diagram of search process [16]

3.2. Review findings

3.2.1. Participant characteristics

All included studies examined the perceptions of PwMS or HCPs concerning wearables for MS management. All studies included adult patients (aged 18 and older), however one examined fitness tracker use among older PwMS (aged 60 and above) [17]. Another study had a sample of only female participants, which may be related to only studying patients with

Relapsing Remitting MS (RRMS), which has higher prevalence among females [18]. Four of the included studies focused entirely on PwMS [17], [18], [24], [20]. Two studies included PwMS among broader samples, including patients with other conditions (e.g., spinal cord injury, acquired brain injury major depressive disorder and epilepsy) [21], [22].

Four studies explored HCPs' perceptions of using wearables in MS [23], [24], [25], [26], and one study [19] explored the satisfaction of both patients and physiotherapists with gait training using the EKSO GT® exoskeleton (Figure 3).

3.2.2. Characteristics of included studies

3.2.2.1. Study design

Five of the included studies (50%) were qualitative design studies. Three used semi-structured interviews [18], [20], [23], while one used unstructured interviews [26], and one used focus group discussions [22]. The other studies collected quantitative data through questionnaires [17], [19], [21], [24], [25] (Figure 3).

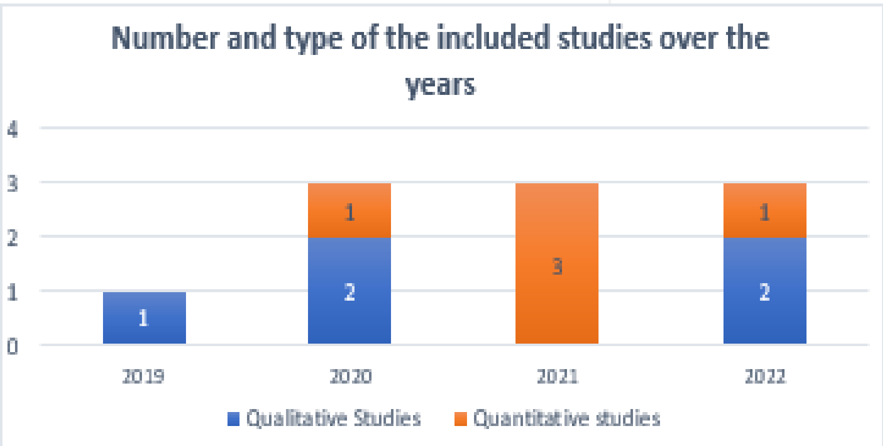

Figure 2: Number and type of the included studies over the years.

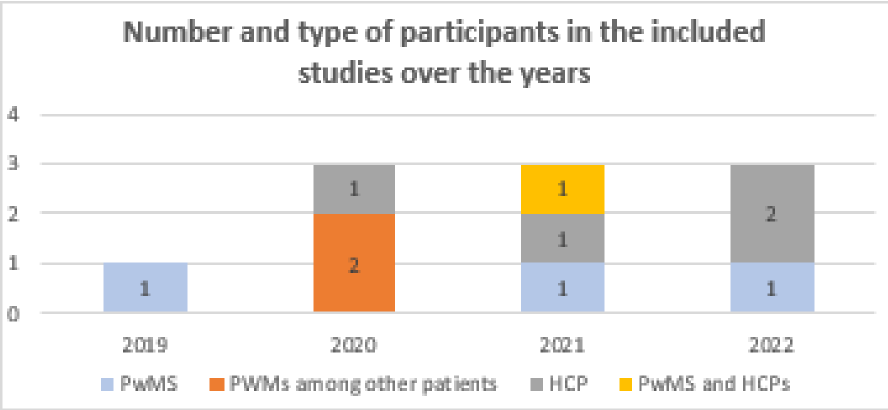

Figure 3: Number and type of participants in the included studies over the years

3.2.2.2. Country

Four of the included studies were undertaken in the UK [20], [22], [23], [25]; three studies were conducted in the USA [21], [26], [22], one each was conducted in Spain [19] and the Netherlands [18], while another was pan-European [24], with the majority of participants being from the UK (Table 2). All the studies were published between 2019-2022.

3.2.3. Characteristics of interventions and outcome measurements

The majority of included studies (80%) were non-interventional studies, only two explored the satisfaction of MS patients and HCPs after the use of wearable exoskeleton device [19], [21]. Tables 3 and 4 summarize both the technologies and the extracted findings concerning perspectives of PwMS and HCPs (respectively), which are discussed in detail in the following subsections.

Study	Facilitators			Barriers	
	Perceived usefulness and accessibility	*Perceived ease of use*	*Awareness and motivation*	*Anxiety and frustration*	*Complexity and design of the wearables*
Remote measurement technology (RMT)					
Andrews et al. (2020) [23]			✗	✗	
Simblett et al. (2020) [22]	✗				
Andrews et al. (2021) [24]					
Andrews et al. (2022) [25]				✗	
Wearable exoskeleton					
Fernández-Vázquez et al. (2022) [19]	✗	✗			
Poritz et al. (2020) [21]		✗			✗
Wearable sensors and activity trackers					
Fortune et al. (2022) [20]	✗	✗	✗	✗	✗
Silveira et al. (2021) [17]	✗				
Wendrich et al. (2019) [18]				✗	✗

Table 1: Summary of findings – MS patients' perceptions of wearable technologies

Study	Facilitators		Barriers	
	Perceived usefulness	*System requirements*	*Data security concerns*	*Increased workload, limited effectiveness*
Remote measurement technology (RMT)				
Andrews et al. (2021) [24]	✗	✗	✗	✗
Andrews et al. (2022) [25]	✗	✗	✗	
Wearable exoskeleton				
Fernández-Vázquez et al. (2021) [19]	✗			
Wearable sensors and activity trackers				
Wendrich et al. (2019) [18]	✗			
Seals et al. (2022) [26]	✗			

Table 2: Summary of findings – HCPs' perceptions of wearable technologies

3.2.3.1. Remote measurement technology (RMT)

Four of the included studies were conducted to explore the use of RMT, which refers to the use of wearable devices and smartphone apps to collect data on human behavior and physical parameters [22], [23], [24], [25]. In terms of the type of device, Andrews et al. (2021) [24] showed that wearable sensing devices were typically reported to be used for passive activity and sleep monitoring, followed by a lower percentage of patients using wearables for weight management and monitoring specific conditions. However, no identification of the specific type of wearables was provided in the study.

3.2.3.2. Wearable exoskeleton

Two studies explored the satisfaction of MS patients and HCPs after the use of wearable exoskeleton device [19], [21]. In neurorehabilitation, exoskeletons can mimic natural walking patterns, perform more intensive therapy with more repetitions, maximize monitoring time, and measure gait characteristics while receiving therapy [27].

3.2.3.3. *Wearable sensors and activity trackers*

Another type of technology identified was the Yamax SW-200 Digi-walker pedometer [20], and various fitness trackers, including Fitbit®, smartphone apps, Apple® watch, and Garmin; other fitness trackers included pedometers and other smart watches were also used by PwMS [17]. The Digi-walker pedometer is low-cost device that can be used to measure physical activity with acceptable accuracy [28]. Another study explored user experience after using Fitbit Charge 2 (Fitbit Inc, San Francisco, CA) activity tracker and the Mijn Kwik (MS sherpa BV, Nijmegen, the Netherlands) smartphone app over four weeks, and reported generally positive perceptions of ease of use and effectiveness [18].

3.2.4. Patient-perceived facilitators of use

3.2.4.1. *Perceived usefulness and accessibility*

Among all the included studies, 28% of PwMS aged 60 and older used a fitness tracker including Fitbit®, smartphone apps, Apple® Watch, and Garmin® to monitor their condition. This rate is lower than the use of fitness trackers among PwMS of all ages, but higher than the general population of older adults [17]. Wearables were linked to higher income, fewer disability, and more employment in this sample. RMT is mostly used to measure and predict relapse in relapsing-remitting MS [22] Participants emphasized assessing vision, fatigue, social functioning, mental health, wellbeing, and activity.

3.2.4.2. *Ease of use*

Participants in one study (42.86% PwMS, and 57.14% with other conditions) reported being satisfied with how much energy was required to stand and move with using two types of wearable exoskeletons, and with the simplicity of strap installation, speed of walk, comfort, and the amount of time and experience required to walk independently [21]. Another study assessed satisfaction among PwMS and HCPs with training with EKSO GT® evaluated by QUEST 2.0 (the Quebec User Evaluation of Satisfaction with Assistive Technology), and found good general satisfaction, with a moderate score for the ease-of-use item [19]. The practicality of waist attachment to various clothing and the security of device placement had an impact on perceived ease of use and the decision to continue monitoring among PwMS [20].

3.2.4.3. Awareness and motivation

Using fitness trackers and mobile app increased awareness of physical status among PwMS by providing them with quantitative data related to their physical performance and sleeping, participants also expressed their willingness to adopt such a technology if it would provide more personalized goals [18]. Using a pedometer increased activity awareness among patients, and helped them set their activity goals and reflect on their daily performances and recognize their inactive periods, and to adjust their behavior in response [20]. In clinical terms, this represents increased patient self-efficacy and engagement.

One participant with MS reported that she was more motivated to achieve her daily activity goal when using the pedometer: “It was quite a positive re-enhancement” [20]. Increasing patients’ engagement in their care plans by empowering them with data could be motivational. For example, using technology could increase motivation between visits, instead of patients waiting until their next routine appointment with an HCP to receive encouragement to walk more, providing supporting ancillary and complementary sources of motivation [26].

3.2.5. Patient-perceived barriers to use

3.2.5.1. Anxiety and frustration

The use of wearables might cause obstacles for patients, including increased anxiety and stress about meeting their daily goals (e.g., number of steps), when in practical everyday life they may not always be able to do so [18], [23], [25]. For example, the use of pedometers was identified as a source of frustration for many patients due to their perception of being harried into reaching their goals and behaving in accordance with “reminders” [20].

3.2.5.2. Complexity and design of the wearables

Participants were unsatisfied about their capacity to walk on uneven or slanted surfaces, climb stairs, and carry objects while walking using wearable exoskeletons. They also expressed the need to improve the size and ease of wearing robotics for walking and driving, in order to facilitate use in the community and the home [21].

User confidence in the accuracy of the pedometer was reduced by placement issues, decreasing its utility as a monitoring device among PwMS. According to Fortune et al. [20], women with bladder urgency found it difficult to remove the pedometer from their hips when using the lavatory. About a third of participants in the same study had trouble opening and shutting the pedometer to check their step count on the digital display throughout the day. Fitbit made data interpretation difficult; one respondent questioned if a test score or sleeping pattern was normal, and how to act on the data [18].

3.2.6. HCP-perceived facilitators of using wearables

3.2.6.1. Perceived usefulness

Andrews et al. [24] collected data via surveys regarding HCPs' usage of apps and RMT by their patients (with depression, epilepsy, and MS) in Europe. They reported that the vast majority (78%) of HCPs said that their patients used RMT (one or more smartphones, wearables, and other devices) to monitor or take better care of their health, or increase awareness of their health.

In a subsequent study, a similar proportion (73.2%) of HCPs for patients with depression, epilepsy, and MS agreed that their services would benefit from implementing RMT in patient care plans, and suggested that RMT data would be beneficial before and during patient consultations with a patient [25]. Furthermore, HCPs stated that RMT might have potential usefulness in MS targeting the variables of activity, anxiety, cognition, fatigue, mood, pain, QoL, and visual acuity.

HCPs emphasized the need for patients to have access to their own data, so that they may become empowered and more involved in their own care. This might include, for instance, moving up appointments, if RMT data showed a pressing need to do so [23]. HCPs stated that using technology could empower patients by enabling them to interpret their data in a more active manner, with increased awareness of their conditions [18], [23], [25]. Physiotherapists were satisfied with the use of the exoskeletons among PwMS; satisfaction with combining the device with other gait trainings was highly correlated with the amount of time spent in neurology rehabilitation [19].

3.2.6.2. System requirements

In order to implement RMT in the care pathway in the most useful way, HCPs mentioned one-to-one training or education to deal with particular cases as they happened or as needed by users [25]. HCPs would use RMT if they could reliably identify relapse, help manage the patients, and provide extensive information about patients' health state. They also believed that their services would likely or highly likely benefit from the use of RMT [25]. HCPs (across the conditions of epilepsy, MS, and depression) highlighted that the speed of accessing patient data is a priority, as well as transferring such data to electronic patient records, and visualizing data in graphs to facilitate analysis and comprehension for both patients and HCPs [23].

3.2.7. HCP-perceived barriers to use

3.2.7.1. Data security concerns

Technical issues such as data accuracy, security, and lack of integration between new and existing systems utilized by HCPs were identified as concerns among the latter, although they stated that they would use them even with less data accuracy, as long as clinicians were aware of the data's possible margins of error [23]. Confidentiality and data protection were identified as barriers to adopting technology by participants [25].

3.2.7.2. Fears of increased workload and limited care plan effectiveness

Participants suggested that an alert-based system would help monitor parameters like fatigue in MS, but they concerned that responding to such alerts would increase HCPs' workload. Instead, they suggested that the patient act autonomously and not immediately contact HCPs [23]. HCPs noted that RMT could never replace face-to-face consultations in MS care, since they need to perform frequent physical exams and observe the patient to detect subtle indications. RMT was primarily seen as a complementary resource for patients [23].

3.2.8. Theoretical frameworks

Fernández-Vázquez et al. [19] employed QUEST 2.0, a standardized form with 12 items to measure user satisfaction and dissatisfaction. This tool is based on research from the early 1990s, and was developed “based on the theoretical and practical foundations of assistive technology as well as on the concept of satisfaction” [29]. While the more recent 2.0 version’s psychometric properties were still found to be valid and reliable for diverse populations by a recent systematic review [30], there is a clear need for more updated and coherent theoretical models of technology acceptance in healthcare research to support evidence-based practice, as most studies continue to use ad hoc measurements and concepts [31].

Apart from Fernández-Vázquez et al. [19], Andrews et al. [23] briefly and superficially alluded to using the technology acceptance model (TAM), which has long been a staple of research on technology acceptance in diverse fields, including healthcare [32]. The other studies we reviewed did not use a coherent theoretical framework to evaluate wearables [25], [24], [20], [21], [26], [17], [22], [18], although terminology such as “perceived usefulness” is suggestive of implicitly using aspects of TAM.

4. Discussion

4.1. Wearable technology in MS

The review identified three types of wearables commonly used with PwMS: activity trackers and wearable sensors, wearable robotic exoskeletons, and RMT. They were deployed to measure activity, fatigue, sleeping pattern, and deterioration in relapses.

It should be noted that certain studies considered technologies beyond wearables, which were not included in this review, to support the activities of PwMS. For example, additional wearables identified in the literature include transcranial direct current stimulation (tDCS), which is a non-invasive brain stimulation technique used as a part of telerehabilitation programs, to improve accessibility and reduce traveling time and cost among PwMS in urban settings in the USA [36]. Another study investigated the feasibility and acceptance for gait rehabilitation of healthy participants, PwMS, and stroke patients using an immersive virtual reality head-mounted display (HMD), and showed increased in walking speed and good acceptance to use the HMD-based training compared to semi-immersive VR and conventional treadmill training [34].

Such technologies were not encompassed in the literature search, as they might be at an early stage of adoption, and no studies identifying the usability and acceptability of such technologies were retrieved.

4.2. User perception regarding wearables

This review explored literature concerning the perceptions of patients and HCPs about using wearables in MS management and, highlighted the perceptions of users by synthesizing evidence to identify barriers and drivers to technology use. The findings broadly align with those of another recent review by Kang and Exworthy [35], which highlighted the role of wearables in empowering individuals to take more responsibility for their own health. It emphasized the role of wearables in changing behavior (as a motivational tool and as a source of self-efficacy), and identified some barriers to technology adoption, such as the design of technological tools themselves, cost, data privacy concerns, and unreliability and inaccuracy of data, which were also confirmed in the current study's findings.

Dehghani and Kim [36] examined how smartwatch design, screen size, and distinctiveness affect users' purchasing intentions and influence the behavioral intentions of both current and potential users, and female users' behavior was found to be more likely to be influenced by such factors. For example, the design of new smart devices is not centered on gender preferences or the situation (e.g., workplace, party); therefore, and in order to attract female users, technology companies must build smartwatches with features beyond functionality [36].

Similar to the findings of the current study, wearables' design and the age and gender of users affect usability, as well as the ability to interpret data and avoid misreading it, in order to achieve effective use [39].

HCPs also play a significant role in encouraging patients to use technology and provide additional support for individual who need to be encouraged, guided, and supported to adopt a more proactive role in managing their health, as well as having the skills to use wearables to be used in risk stratification and early intervention [35].

There are numerous potential drivers of using wearables among patients and HCPs, and the literature raised some potential risks of using wearables in family medicine. In particular, the constant measurement of biomedical data appeared to be potentially anxiety provoking, according to GPs. As a result of consumer factors (i.e., intrusive fitness apps and prioritizing quick information to reinforce a fast-paced lifestyle), individuals' mental health could be affected, and HCPs' workload could be increased [40]. Similar risks of anxiety and frustration associated with wearables were mentioned by patients in three reviewed studies [18], [23], [25], which one of which noted HCPs' concerns about the potential increase of their workload by having to analyze voluminous ancillary information not necessarily medically pertinent for normal healthcare service delivery [23].

Watt et al. [39] highlighted concerns about the prohibitive costs of short-term wearables adoption. While long-term savings might be achieved if implementing wearables as part of preventive care, HCPs do not generally consider this to be an objective in the current use of such technologies. The potential reduction of cost is a result of decreased admission to emergency and hospitalization and increased autonomy and self-management among individuals [39]. Therefore, future studies might investigate the economic effect on implementing wearables in managing MS. For example, saving traveling time and reducing the cost of care over the long term, alongside potential increased autonomy and self-management among individuals including improved healthy behavior [35]. Therefore, future longitudinal studies need to empirically investigate the economic impacts of implementing wearables in managing MS over the long term in order to support evidence-based practice in this regard.

4.3. Theoretical frameworks

Surprisingly, there was a noticeable absence of theoretical frameworks for technology acceptance in the included studies. As presented in section 3.2.8, only one study used a theoretical model of technology in earnest [19], and another alluded to TAM superficially [23]. There is a clear and pressing need for studies grounded in respected technology acceptance theoretical frameworks to support evidence-based use of appropriate technologies in practice, for PwMS and other patient groups.

Numerous theoretical models and their adaptations have been developed to understand technological acceptance and attitudes across fields, including healthcare [42]. A comprehensive systematic review found that the TAM theory is the most commonly used in smart wearables studies, followed by the Diffusion of Innovation Theory (DOI), the Unified Theory of Acceptance and Use of Technology (UTAUT), and its revised version, UTAUT2 [42].

It is essential to implement robust theoretical models in the use of technology in healthcare, with a particular focus on smart wearables for PwMS. This approach will direct future studies to have an in-depth understanding of the factors influencing users' adoption of technology. Understanding individuals' views, beliefs, assumptions, and subjectivity is commonly evaluated by using questionnaires and surveys.

5. Limitations

To the best of our knowledge, this is the first scoping review that explored both the perceptions of patients and HCPs concerning using wearables in MS. The relatively limited number of recent studies investigating the perceptions of PwMS and HCPs about using wearables reflects the novel and emergent nature of wearables *per se*. Moreover, the small size of samples in some studies, and varying conditions, should be considered when interpreting the findings of this study, especially as some of the studies included PwMS as part of larger samples of a range of conditions.

Further studies focusing on MS patients are required to understand the particular perceptions of both patients and HCPs in MS care, in order to make the best use of wearables. The context of studies was limited to a few developed countries that have the ability to provide technology solutions to users; therefore, users` experiences and perceptions to use technology in MS in developing countries remain unexplored.

Finally, while conducting this scoping review, the inter-rater reliability between the reviewers was not measured during the selection process of the studies, but the authors followed the PRISMA-ScR guidelines. This scoping review aimed to map the literature rather than assessed research quality, therefore we did not employ inter-rater reliability due to the nature of the study and the limited time to conduct it. Although inter-rater reliability remains essential for the initial screening and selection of studies, it would be beneficial to prioritize the use of inter-rater reliability indicators in the future to guarantee consistent study selection among reviewers [43].

6. Conclusion

This scoping review identified the main wearables used in PwMS, and the potential facilitators and barriers for the further adoption of the technology. Furthermore, it identified knowledge gaps related to wearable application in healthcare practice, managing diseases, device usability and functionality, and user acceptance.

User perceptions were investigated concerning limited types of wearables, reflecting the need for evidence-based literature supporting the hypotheses that technology would empower users in healthcare. PwMS were motivated to use wearable devices due to perceived usefulness, ease of use and motivation, but complexity and design of the wearables caused anxiety and frustration in many cases.

HCPs are willing to use wearables devices as they embrace the usefulness of the system for their patients. Regarding typical usage obstacles, like technological difficulties, privacy worries, anxiety, and increased workload, user opinions and views should also be considered in designing and implementing technology in MS care, to obtain the potential advantages of wearables and increase positive reinforcement among users.

CRediT authorship contribution statement

SA: Conceptualization, Project administration, Writing – original draft, Writing – review & editing, Visualization, Methodology, Formal analysis, Investigation. SK: Conceptualization, Project administration, Validation, Resources, Writing - Review & Editing, Visualization, Supervision. HW: Conceptualization, Project administration, Validation, Resources, Writing - Review & Editing, Supervision.

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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.

Summary table

What was already known on the topic

- Wearable technologies can track MS patients’ health, activity levels, and disease progression.
- Despite the availability of various wearables for disease management, little is known about MS and stakeholders’ perspectives on their use, potential barriers, or factors that may affect their usability and acceptance.

What this study added to our knowledge

- The study identifies perceived facilitators and barriers of wearables among MS patients and HCPs.
- There is a need for more robust theoretical frameworks to study technology adoption issues in the context of MS care, considering the perspectives of patients and HCPs.

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Appendix: Search Strategy

Database: Ovid MEDLINE(R) ALL <1946 to January 13, 2023>

Search Strategy:

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1. (Multiple Sclerosis or Multiple Sclerosis or disseminated sclerosis or encephalomyelitis disseminate or Relapsing remitting MS or Primary progressive MS).mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms] (97070)
2. Wearable technology.mp. or exp Wearable Electronic Devices/ (18818)
3. Wireless Technology.mp. or exp Wireless Technology/ (4931)
4. fitness tracker.mp. or exp Fitness Trackers/ (1200)
5. exp Accelerometry/ or exp Fitness Trackers/ or fitbit.mp. (13191)
6. smartwatch.mp. (651)
7. wrist band.mp. (62)
8. smart glasses.mp. or exp Smart Glasses/ (291)
9. Wireless Technology/ or exp Remote Sensing Technology/ or wireless sensors.mp. (9600)
10. smart clothing.mp. or exp Smart Materials/ or Wearable Electronic Devices/ or Transcranial Direct Current Stimulation.mp. or Transcranial Direct Current Stimulation/ (14967)
11. Motor Activity/ or Accelerometery/ or accelerometer.mp. or Sedentary Behavior*/ (112033)
12. 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 (153804)
13. 1 and 12 (835)

14. exp Patient Satisfaction/ or exp "Surveys and Questionnaires"/ or patient perception.mp. or exp Attitude to Health/ (1524520)
15. physician perception.mp. or "Attitude of Health Personnel"/ (130835)
16. exp "Surveys and Questionnaires"/ or nurse perception.mp. or exp Perception/ or "Attitude of Health Personnel"/ (1724140)
17. exp Attitude to Health/ or patient belief.mp. or exp "Surveys and Questionnaires"/ (1523507)
18. exp Patient Satisfaction/ or exp Patient Participation/ or exp "Surveys and Questionnaires"/ or patient view.mp. (1283170)
19. "Delivery of Health Care"/ or patient experience.mp. or "Quality of Health Care"/ (191526)
20. Occupational Therapists/ or exp Occupational Therapy/ or occupational therapist perception.mp. (14901)
21. Physical Therapists/ or physiotherapists perception.mp. (2982)
22. 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 (2194028)
23. 13 and 22 (213)
24. (Multiple Sclerosis or Multiple Sclerosis or disseminated sclerosis or encephalomyelitis disseminate or Relapsing remitting MS or Primary progressive MS).mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms] (97070)
25. Wearable technology.mp. or exp Wearable Electronic Devices/ (18818)
26. Wireless Technology.mp. or exp Wireless Technology/ (4931)
27. fitness tracker.mp. or exp Fitness Trackers/ (1200)
28. exp Accelerometry/ or exp Fitness Trackers/ or fitbit.mp. (13191)
29. smartwatch.mp. (651)
30. wrist band.mp. (62)
31. smart glasses.mp. or exp Smart Glasses/ (291)

32. Wireless Technology/ or exp Remote Sensing Technology/ or wireless sensors.mp. (9600)
33. smart clothing.mp. or exp Smart Materials/ or Wearable Electronic Devices/ or Transcranial Direct Current Stimulation.mp. or Transcranial Direct Current Stimulation/ (14967)
34. Motor Activity/ or Accelerometery/ or accelerometer.mp. or Sedentary Behavior*/ (112033)
35. 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 (153804)
36. 24 and 35 (835)
37. exp Patient Satisfaction/ or exp "Surveys and Questionnaires"/ or patient perception.mp. or exp Attitude to Health/ (1524520)
38. physician perception.mp. or "Attitude of Health Personnel"/ (130835)
39. exp "Surveys and Questionnaires"/ or nurse perception.mp. or exp Perception/ or "Attitude of Health Personnel"/ (1724140)
40. exp Attitude to Health/ or patient belief.mp. or exp "Surveys and Questionnaires"/ (1523507)
41. exp Patient Satisfaction/ or exp Patient Participation/ or exp "Surveys and Questionnaires"/ or patient view.mp. (1283170)
42. "Delivery of Health Care"/ or patient experience.mp. or "Quality of Health Care"/ (191526)
43. 37 or 38 or 39 or 40 or 41 or 42 (2180706)
44. 36 and 43 (210)

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Table 1

	Inclusion criteria	Exclusion criteria
Types of participants	Studies that include PwMS who exhibit mild, moderate, or severe disability at any age (e.g., children and adults), to avoid any inclusion bias. Since the outcomes associated with the technology may vary from patient to patient, and depending on whether the interventions are part of primary care or rehabilitation programs, the review included studies that considered the perspectives of physicians, nurses, occupational therapist, and physiotherapists, in order to gain a more comprehensive understanding of the topic.	Studies that focused on neurological conditions other than MS were excluded.
Concept	Studies focused on the use of wearable technologies in managing MS to measure any potential related outcome, such as gait, movement, activity, upper limb function, fatigue, balance, and cognition. Studies with objectives that interested in perceptions of using the wearable technology were included in this review. Studies reporting quantitative or qualitative data on perceptions, experiences, views, perspectives on usability, satisfaction, barriers, and facilitators of PwMS or HCPs were included.	Studies that focused on technologies that did not meet the used definition of wearable technologies were excluded. Studies with different objectives, such as using technology to investigate other outcomes (e.g., steps, adherence to program but not interested in evaluating the user experience of technology) were excluded.
Context	Interventions can be used at different settings, including home monitoring, rehabilitation programs, and primary healthcare settings. The geographical context encompasses all countries worldwide. No restrictions were imposed on the publication year of articles, although the field of wearable technology is recent anyway (thus there	

	is no need for a time restriction, as studies on this subject are relatively new by default).	
Types of sources	All types of studies in this review were included (except protocols and conference papers) to explore the topic area and retrieve any related literature and identify a breadth of good quality reference. It is recommended to keep the source of information “open” in scoping reviews, to allow for the inclusion of all types of evidence.	Protocols and conference papers were excluded.

Table 1: Eligibility criteria for study selection

Studies and countries	Aims/objectives	Theoretical model	Sample	Methods (tools, designs)	Intervention	Outcomes
Andrews et al. (2022) [25] UK	To establish HCPs' practical requirements for clinical integration of RMT data.	Not specified; 'perceived benefit'	106 HCPs	Survey Quantitative study	NA	73.2% said their service would benefit from RMT in patient care plans. RMT data may be reviewed before and during patient consultations.
Andrews et al. (2021) [24] UK	To explore opinions and experiences of HCPs on the use of smartphone apps and remote measurement technology RMT.	Not specified: 'perceived performance, social influence and organizational context'	1006 HCPs	Survey Quantitative study	NA	78% indicated that patients used RMT to improve or increase health awareness. Wearable sensing devices are most commonly reported to be used for passive monitoring of activity and sleep.
Andrews et al. (2020) [23] UK	To understand HCPs' perspectives on using RMT in healthcare practice for the care of patients with depression, epilepsy, or MS.	TAM	26 HCPs	Semi structured interviews Qualitative study	NA	8 main themes: (1) potential clinical value of RMT data; (2) when to use RMT in care pathways; (3) roles of health care staff who may use RMT data; (4) presentation and accessibility of data; (5) obstacles to successful use of RMT; (6) limits to the role of RMT; (7) empowering patients; and (8) considerations around alert-based systems.
Fernández-Vázquez et al. (2021) [19] Spain	To explore the patients' and physiotherapists' satisfaction from gait training with the EKSO	Not specified	54 participants:	Quebec User Evaluation with Assistive Technology and Client Satisfaction	EKSO GT® gait rehabilitation lower limb wearable	This study demonstrates a good degree of satisfaction for PwMS (31.3 ± 5.70 out of 40) and physiotherapists

	GT® exoskeleton in PwMS.		40 PwMS and 14 physiotherapists	Questionnaire (QUEST 2.0) Observational/ cross-sectional study Quantitative	exoskeleton. All robotic movements and parameters managed by external controller, stored on magnetic backpack seat.	(38.50 ± 3.67 out of 45 points) with the EKSO GT®
Fortune et al. (2022) [20] UK	This study evaluated user experience of the Yamax SW-200 Digi-walker pedometer in a group of PwMS.	Not specified	15 PwMS	Semi-structured interviews; iStep-MS trial Qualitative study	NA	Overarching theme of frustration with using pedometers. Three subthemes: (1) increasing activity awareness, (2) numeric motivation, (3) (Un)usability.
Poritz et al. (2020) [21] USA	To provide the results of a robotic exoskeleton user satisfaction questionnaire completed by participants utilizing two robotic exoskeletons.	Not specified	7 participants (3 PwMS)	Questionnaire Quantitative study	2 exoskeleton-assisted training phases with the REX and the Ekso 1.1 (Ekso), and subsequent user satisfaction questionnaire	Participants indicated high satisfaction with transferring in and out of the REX and with its appearance, and high satisfaction with the transportability of the Ekso. Expectations for exoskeleton use were relatively similar for the two devices. Participants suggested modifying both exoskeletons, and they would use both exoskeletons at home and in the community if they were available.

Seals et al. (2022) [26] USA	To characterize different clinical challenges and explores how the potential benefits of new evidence-based practices enabled by wearable sensors might be integrated into future practices.	Not specified	10 experienced clinicians	Unstructured interviews Qualitative study	NA	Clinicians value quantitative sensor data within a whole patient narrative, to help track specific rehabilitation goals, but identify a tension between grasping critical information quickly and more detailed understanding.
Silveira et al. (2021) [17] USA	To report on the rates and patterns of fitness tracker use in PwMS aged over 60 years.	Not specified	440 PwMS	Survey Quantitative study	NA	112 (28%) identified as fitness tracker users. The most common activity monitors were Fitbit®, Smartphone app, Apple® watch, and Garmin®. Fitness tracker users mostly reported having relapsing-remitting MS, less disability, higher income, and higher rates of employment. There was a statistically significant difference in GLTEQ and GLTEQ-HCS scores between fitness tracker users and non-users.

Simblett et al. (2020) [22] UK	To conduct a consultation exercise on the clinical end point or outcome measurement priorities for RMT studies, drawing on the experiences of people with chronic health conditions.	Not specified	24 participants (9 PwMS)	Focus group discussions Qualitative approach	NA	Participants emphasized the importance of measuring additional symptoms, such as vision, fatigue, and social functioning. Mental health was also thought to be important to measure. Some participants spoke of the value in measuring holistic wellness indicators (e.g., diet and physical activity).
Wendrich et al. (2019) [18] Netherlands	To indicate potential benefits and challenges and identify the needs and wishes of regarding the use of digital self-monitoring tools, particularly smartphone apps and activity trackers, by PwMS.	Not specified	7 PwMS	Semi structured interviews Exploratory/ qualitative study	NA	The smartphone app and the activity tracker increased respondents' awareness of their physical status and stimulated them to act on the data. Challenges, such as confrontation with their MS and difficulties with data interpretation, were discussed. The respondents desired (1) adaptation of digital self-monitoring tools to a patient's personal situation, (2) guidance to increase the value of the data, and (3) integration of digital self-monitoring into treatment plans.

Table 2: Summary of included studies

- **Declaration of Interest Statement**

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

Author Statement

- **CRediT author statement**

SA: Conceptualization, Project administration, Writing – original draft, Writing – review & editing, Visualization, Methodology, Formal analysis, Investigation. SK: Conceptualization, Project administration, Validation, Resources, Writing - Review & Editing, Visualization, Supervision. HW: Conceptualization, Project administration, Validation, Resources, Writing - Review & Editing, Supervision.