Current State of Connected Sensor Technologies used during Rehabilitation Care: Scoping Review Protocol

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Abstract

Background: Connected sensor technologies can capture data using algorithms to generate measures of behavioral or physiological function. Previous research of such products has focused on design, development, and validation. Some reviews have either summarized general technological solutions to address specific behaviors such as physical activity or focused on remote monitoring solutions in specific patient populations.

Objective: To map research that focuses on using connected sensor technologies to augment rehabilitation services.

Methods: The Population, Concept, and Context framework was used to define inclusion criteria. Relevant articles will be included if the sample included adults (population), the intervention used at least one connected sensor technology and involved data transfer to clinician so that it could be used to inform the intervention (concept), and the intervention relates to rehabilitation (context). An initial search strategy will be built in Embase, peer reviewed, and then translated to Ovid MEDLINE ALL, Web of Science Core Collection, and CINAHL. Duplicates will be removed prior to screening articles for inclusion. Two independent reviewers will screen articles in two stages: title/abstract and full text. Discrepancies will be resolved through group discussion. Data from eligible articles relevant to population, concept, and context will be extracted. Descriptive statistics will be used to report findings, and relevant outcomes will include the type and frequency of connected sensor used and method of data sharing. Additional details will be narratively summarized and displayed in tables and figures. Key shareholders will review results to enhance interpretation and trustworthiness.

Results: The results of this scoping review are expected in October 2024.

Conclusions: Results from the scoping review will identify critical areas of inquiry to advance the field of technology augmented rehabilitation. Results will also support the development of a longitudinal model to support long-term health outcomes. Clinical Trial: Open Science Framework (osf.io/jys53).

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Review registration number: Open Science Framework (osf.io/jys53).

Keywords: connected sensor technology; digital health; rehabilitation; remote monitoring; telehealth

Introduction

Connected sensor technologies are defined as “technology products that process data captured by mobile sensors using algorithms to generate measures of behavioral and/or physiological function” [1]. Examples include medical technologies such as ingestibles (smart pills) and dermal patches along with direct-to-consumer wearables that include activity trackers, heart rate monitors, and smart clothing. Consumer wearables have grown in popularity and ownership over the past decade for a variety of reasons. A 2016 market research survey reported that consumers were motivated to buy wearable technologies to support health, and consumers noted benefits of wearables that include enhancing accountability, improving exercise habits, and becoming more efficient at home and work [2]. These motivations for ownership have stayed consistent over the years. In fact, the American College of Sports Medicine annual survey for fitness trends revealed that wearable technology was predicted to be the top trend in fitness in the United States for 2024—a trend that has been in the number one spot for seven of the previous nine years [3]. This survey also highlighted a new trend for 2024—data-driven training technology—that was defined as using real-time data output such as heart rate to guide workouts [3].

In addition to consumer uptake, healthcare systems and providers are beginning to adopt connected sensor technologies. A driving factor for health system uptake is the need to deliver healthcare services to more people at lower costs due to an aging population with high rates of non-communicable diseases [4]. One approach to reduce costs while promoting better health is through reallocation of funds to preventative services such as primary care [5] and lifestyle modification programs such as those that promote physical activity. Common limitations of these programs, however, are that maintenance beyond 1 year has not been established [6] and cost-effectiveness is unclear [7]. Alternatively, funds could be used to support remote monitoring programs that use connected sensor technologies with the goal of preventing unnecessary healthcare utilization. In theory, earlier detection of health deterioration or nonadherence, such as in patients with chronic

obstructive pulmonary disease or heart failure, would prompt early, at-home intervention, thus, reducing emergency department visits and hospitalizations. While evidence to support such mitigation is mixed [8], increased adherence was associated with reduced risk of subsequent hospitalization and death [9] suggesting that a remote monitoring approach may be beneficial for some patients.

Despite increasing popularity among consumers and healthcare systems, the role of connected sensor technologies in rehabilitation remains unclear. Potential benefits of using patient data from sensor technologies include deeper insights on treatment effectiveness, health behaviors, and symptom patterns [10-12]. However, there may also be negative effects to using such data. Both patients and providers recognize that consumer-grade devices may report inaccurate data [10, 11], and they have concerns about data privacy, how to manage and use collected data, and what specific data should be shared [10-12]. Malalignment of patient and provider expectations may contribute to tensions within the therapeutic relationship [13].

As such, there is a need to evaluate how connected sensor technologies can be used effectively to enhance rehabilitation services. The use of connected sensor technologies in rehabilitation practice is relatively new and much remains unknown given the complexity of available sensor types and heterogeneous patient populations. Most prior studies have focused on development and validation of connected sensor technologies [14-16] and the infrastructure necessary to support data sharing and cloud computing [17, 18]. Previous reviews have focused broadly on technological solutions to address specific behavior interventions such as weight loss [19], while others have focused on tools capable of assessment and remote monitoring of specific patient populations—cardiac [20], pulmonary [21], neurological [22], and cancer [23]. To our knowledge, no review has focused on the use of connected sensor technologies to inform rehabilitation interventions. Such a review would identify the breadth of research, identify knowledge gaps, and elucidate directions for future study while providing clinicians with case

examples of how to implement connected sensor technologies into rehabilitation practice.

The aim of this scoping review is to discover and map research that focuses on using connected sensor technologies to augment rehabilitation care. The general research question guiding this aim was: What is known from existing literature about the remote use of connected sensor technologies integrated into rehabilitation care to monitor patient status and inform care decisions?

Methods

The scoping review will be conducted in accordance with the JBI methodology for scoping reviews [24, 25], and in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews [26]. We will also follow the six-stage framework for a scoping review proposed by Arksey & O'Malley [27].

Stage 1: Identifying the Review Questions

The first stage in the scoping review as outlined by Arksey & O'Malley [27] was to identify specific questions to help guide the search strategy and answer the general question posed above. Thus, we developed the following specific questions:

1. How have researchers studied the use of connected sensor technologies in rehabilitation (e.g., what types of studies) as part of a feedback loop between patients and providers?
2. Within the context of rehabilitation care, what types of connected sensor technologies have been used, how were they used, and what type of patient generated health data was collected?
3. With what patient populations have these connected sensor technologies been used and what has been found?
4. Have researchers explored various shareholder experiences and perspectives of using connected sensor technologies in rehabilitation, and if so, which shareholder groups are

represented?

5. Based on the scope of research in this area, what are the general limitations and research gaps?

In addition to these questions, we set specific parameters around the research of interest such that each study needed to include: 1) a connected sensor technology; 2) data transfer from the patient to the clinician; and 3) use of the data by the clinician to inform the rehabilitation intervention.

Stage 2: Identifying Relevant Studies

Based on recommendations from JBI, we used the Population, Concept, and Context (PCC) framework to develop initial search terms [25]. These keywords and synonyms will be used to iteratively develop a robust search strategy.

Population

The population for the scoping review will be limited to adults (≥18 years old). If studies include both children and adults, the study may be included if data can be separated between the age groups. If data cannot be separated, then the study will be excluded. We will include all patient populations (e.g., cardiac, pulmonary, etc.). We made this decision because we anticipate that connected sensor technologies used during rehabilitation could be applicable to patient populations other than those studied.

Concept

The concept involves studies that include 1) at least one connected sensor technology product that collects patient data; 2) data transfer from the product and patient to the clinician; and 3) use of the

data by the clinician to inform the intervention. We used the definition provided in The Playbook [1], which defines a connected sensor technology as, “products [that] process data captured by mobile sensors using algorithms to generate measures of behavioral and/or physiological function” (pg. 79). Thus, terms such as connected sensor, remote monitoring, accelerometer, Bluetooth, inertial measurement unit, actigraphy, biomedical technology, remote sensing technology, haptic technology, digital technology, and wearable electronic devices will be considered for the search strategy. To capture the concept of data transfer, we will consider terms such as electronic health record integration, cloud, and dashboard. Because the final concept—use of data by the clinician—is difficult to capture using search terms, we will identify this component during full text review.

Context

The context will include rehabilitation and exercise related studies. As such, the search terms will include rehabilitation, physical therapy, physiotherapy, telehealth, telerehabilitation, digital medicine, and digital health. There will be no other restrictions on the context.

Understanding the context is important to interpret what may be possible in different settings. For example, the Veterans Health Administration (VHA) has been and continues to be a leader in deploying technology solutions for healthcare. The VHA Telehealth Services program office has been in existence for just over 20 years [28] and has established the infrastructure that is necessary to support implementation of rehabilitation practices that leverage remote patient monitoring to inform care decisions. Other healthcare systems may have inadequate infrastructure, which is a significant barrier to clinic-level implementation of patient generated health data.

Search Strategy and Information Sources

A comprehensive literature search will be designed and performed by a medical librarian (CP) in

February 2024 for the concepts of wearable sensors, rehabilitation, and medical health data. The search will be built in Embase and translated to additional databases. Prior to translation, the Embase search strategy will be peer-reviewed by a medical librarian following the PRESS guidelines [29]. Relevant publications will be identified by searching the following databases with a combination of standardized index terms and keywords: Ovid MEDLINE ALL (1946 to February 22, 2024), Embase (via Elsevier, 1947 to present), Web of Science Core Collection (via Thomson Reuters, including Science Citation Index Expanded 1974 to present, and Social Sciences Citation Index 1974 to present), and CINAHL (Cumulative Index to Nursing and Allied Health Literature via EBSCOhost, 1981 to present). When possible, the searches will be limited to adult studies with the publication types of conference abstracts and reviews excluded, and the publication date will be limited to include 2008 to present. See Appendix I for a list of all database search strategies.

Data Management

Following the search, all results will be exported to EndNote 21 (Clarivate Analytics, PA, USA) and duplicates will be initially removed using this reference management software. Results will then be uploaded to Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia) for final duplicate removal and screening.

Stage 3: Article Selection and Eligibility Criteria

This scoping review will consider quantitative, qualitative, and mixed methods study designs for inclusion. While reviews, editorials, and other opinion papers will be excluded, we will manually search such manuscripts for relevant articles. Inclusion and exclusion criteria are summarized in Table 1 according to the PCC framework.

Table 1. Inclusion and Exclusion Criteria

Domain	Inclusion	Exclusion
Population	• Adults (≥18 years old)	• Sample aged <18 years old • Does not involve human subjects (e.g., animals, etc.)
Concept	• Connected sensor technology product • Collects patient data primarily through passive • Data transfer from the participant's connected sensor technology to a clinician • The clinician uses the data to inform an intervention	• Study not related to an intervention (e.g., observational, validation or reliability study, review, opinion, etc.) • No data transfer or data transfer requires ongoing active input from participant (e.g., paper or electronic diary) • The data are not used to inform the intervention (e.g., accelerometry data collected only for study outcome)
Context	• Intervention is relevant to rehabilitation	• Intervention is not relevant to rehabilitation (e.g., medication adherence)
Other		• Full text not available in English

Studies will be screened for inclusion in two stages, and each study will be screened by two independent reviewers during both stages. The first stage will involve screening of titles and abstracts; if there are no clear exclusion criteria, the study will advance to the second stage of screening. The second screening stage is full-text review. Full articles will be retrieved through the University of Colorado library and associated resources, the Department of Veterans Affairs library, and by contacting corresponding authors. If full text cannot be found through reasonable means, then the article will be excluded from the review. If there are discrepancies at either screening stage, the articles will be discussed as a team to arrive upon an agreement. The results of the search will be reported in full in the final scoping review and presented in a PRISMA flow diagram [30].

Stage 4: Data Extraction and Charting

We will develop and pilot a custom data extraction table within Covidence and/or Excel (Microsoft, WA, USA). We will extract article characteristics (e.g., authors, title, journal, year of publication), study characteristics (e.g., study design, country where study was conducted, aim(s), population

studied, etc.), and data pertinent to the scoping review questions. As we are interested in describing what is known about connected sensor technologies integrated into rehabilitation interventions, we will chart technology and data characteristics (e.g., type of connected sensor technology, name and manufacturer, prior validation, type of data collected from the connected sensor technology). We will also describe the method(s) used for data transfer and how the data was used to inform the intervention. The data extraction table will be updated as we become more familiar with the literature and identify salient data to answer our research questions. Further details of planned data extraction are in Table 2.

Table 2. Data extraction plan

Category	Data Extracted
Population	• Sample size • Participant demographics (sex, age, etc.) • Population diagnoses (e.g., chronic obstructive pulmonary disease, congestive heart failure, Parkinsons Disease, etc.)
Concept	• Type of sensor technology • Type of data collected from sensor technology (e.g., heart rate, step count, sleep duration, etc.) • Method of data collection • Data transfer methods • How sensor technology was used • Prior validation • Method of validation (if applicable) • Co-occurring digital health technologies (e.g., artificial intelligence)
Context	• Healthcare system • Type of healthcare setting (e.g., hospital, clinic, home, etc.) • Type of rehabilitation (e.g., physical therapy, occupational therapy, etc.) • Country

Primary data abstraction will be completed by MRR. Then, the data will be checked by a second member of the team for completeness. Any discrepancies that arise will be discussed as a team for resolution. Authors of papers will be contacted when needed to request missing or additional data. Modifications to data extraction will be detailed in the full scoping review.

Stage 5: Data Synthesis

We will first describe the scope of the literature using counts (n), percentages, means, medians, and measures of variance as appropriate. For example, we will describe the number and type

(randomized controlled trial, quasi-experimental, etc.) of studies that have been conducted. We will also describe the number of connected sensory technologies studied by category (accelerometer, magnetometer, etc.), and the populations in which the devices were studied (musculoskeletal, neurological, healthy adults, etc.). These results will be presented in figures and tables. We will then use a narrative approach to describe how connected sensor technologies were used during rehabilitation interventions and to summarize any qualitative data that may be included in the review.

Stage 6: Shareholder Consultation

Once results are synthesized, we will present them to various shareholder groups including patients and rehabilitation clinicians. Shareholder feedback will be incorporated into the results and discussion to afford a broader presentation and interpretation of the findings of the scoping review. We anticipate shareholder input will help identify areas that have been understudied or not studied, situate the results in the context of priorities of various shareholder groups, and identify salient future directions for research.

Results

We conducted initial searches to refine the search strategy. Through this process, we added a date requirement to include studies from 2008 to present. We the scoping review through stage 5 will be completed by October 2024 so that results may be presented to shareholders and then disseminated in a scientific journal.

Discussion

We designed this scoping review to help map how connected sensor technologies have been studied

as an augment to rehabilitation interventions. Results from the scoping review will identify the current state of this research while highlighting critical areas of inquiry to advance this field. Results will also support the development of a longitudinal care model to prioritize long-term health outcomes.

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MRR contributed to the scoping review design, data collection, and drafting and revising the manuscript. RA, SB, AF, and DG all contributed to the scoping review design, data selection, and revising the manuscript. CP contributed to the scoping review design with an emphasis on search strategy and data collection.

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Conflicts of Interest

The authors declare no conflicts of interest.

Abbreviations

CINAHL: Cumulative Index to Nursing and Allied Health Literature

PCC: Population, Concept, Context

VHA: Veterans Health Administration

Multimedia Appendix 1. Search Strategy

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Supplementary Files

Multimedia Appendixes

Search Strategy.
URL: http://asset.jmir.pub/assets/4745cd7c004deb49400b1ceb87a22f0d.docx