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Integration of Sensor-Based Technology in Mental Healthcare: A Systematic Scoping Review

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Abstract

Sensor-based technologies can collect objective and real-time data on physiological, behavioral, and contextual factors related to mental disorders. This not only holds potential for mental healthcare but also comes with challenges, such as handling large amounts of data and supporting the integration of sensors in clinical practice. This systematic scoping review aims to provide an overview of studies explicitly addressing the integration of sensor-based technology in mental healthcare by reporting on the way that therapists and patients work with sensors. In addition, we explore barriers and facilitators for the integration of sensor-based technology in clinical practice. Four databases were searched on April 5, 2023. Studies on sensor-based technology integrated in mental healthcare were included. A total of 14 studies were included. In these studies, a variety of sensor-based technologies were used. All studies were conducted between 2016 and 2022. Most studies showed that sensor-based technologies are accepted by patients and that their use is associated with symptom reduction. However, most studies did not systematically report on barriers and facilitators and mainly focused on the technology itself rather than on the broader context of its intended use. Also, sensor-based technologies are not yet embedded in clinical protocols. From the current review, we can conclude that sensor-based technologies are sufficiently accepted and feasible, and that sensors are promising for enhancing clinical outcomes. However, sensors are not properly integrated in treatment protocols yet. Therefore, we propose a next phase in research on sensor-based technology in mental healthcare treatment. This next phase asks for a multifaceted approach consisting of (1) embedding sensor-based technology in treatment protocols in co-creation with patients and clinicians, (2) examining the feasibility of these interventions together with small-scale evidence studies, and (3) systematically examining the implementation of sensor-based technology in clinical practice using existing frameworks for technology implementation. Open Science Framework: https://doi.org/10.17605/OSF.IO/XQHSY.

Keywords Scoping review · Sensor-based technology · Mental health · Implementation

Introduction

In recent years, there is a rapid development of technologies aimed at different groups of psychiatric patients. One type of technology includes sensors, which provide data about an individual's behavior, physical states, and environments (Mohr et al., 2020). Over the past decade, sensors have become smaller, lighter, and more accurate (Mohr et al., 2017a, b), and with the development of smartphones, smartwatches, and other wearable sensors, the integration of sensor-based data in mental healthcare has become increasingly feasible. For the current systematic scoping review on the integration of sensor-based technology in mental healthcare, sensor-based technology is defined as sensors collecting physical data (e.g., heart rate variability, electrodermal activity) as well as behavioral data (e.g., sleep quality, physical activity). Sensors can collect objective and real-time data on various physiological, behavioral, and contextual factors related to mental disorders, such as depression, bipolar disorder, and schizophrenia (e.g., Sheikh et al., 2021; Tseng et al., 2020). Sensors allow passive sensing: "the capture of data about a person without extra effort on their part" (Cornet & Holden, 2018). In the subsequent sections, we

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will explore both the potential benefits and challenges associated with sensor applications in mental healthcare, followed by a focused examination of the key challenge: the integration of sensors in mental healthcare.

Potential of Sensor-Based Technology for Mental Healthcare

Sensor-based technology holds potential for mental healthcare in various ways. First, sensors can provide insight into a patient's condition, allowing for more accurate assessment and personalized treatment plans (Adler et al., 2022). Passive monitoring of physiological and behavioral data can moreover enable longitudinal tracking of symptoms, thereby offering an objective assessment of a patient's response to an intervention and allowing for early detection of changes in mental health. For example, depression is associated with sleep disruption and social withdrawal, factors that can be accurately measured by sensors (e.g., Berke et al., 2011; Moshe et al., 2021). Early detection of such markers could contribute to timely interventions and potentially prevent escalation of symptoms (Tseng et al., 2020). Second, by collecting and analyzing sensor-based data of people who are already diagnosed with a certain mental disorder, new knowledge can be gained, leading to a broader understanding of mental disorders. For example, associations between GPS-derived location and depressive symptoms of people diagnosed with depressive disorder led to the insight that a lack of mobility may be an early warning sign for depression (Saeb et al., 2016). In this way, sensors have the potential to transform the classification of mental disorders from symptom-based categorization towards person-specific descriptions (Bhugra et al., 2017). Third, sensors can collect data in naturalistic (at-home) settings, facilitating remote monitoring of symptoms. This enables clinicians to remotely assess symptoms and adjust treatment, providing patients with adequate care at distance, while minimizing the clinician's workload (Bhugra et al., 2017).

Challenges Regarding the Use of Sensor-Based Technology in Mental Healthcare

Having access to sensor data holds great potential, but it is a challenge to handle the large amount of data. In order to make the large volume of sensor-based data feasible for clinical practice, specific analytical tools are needed (Torous et al., 2015). These analytical tools not only need to be able to handle large amounts of data but are also challenged by the complexity of mental health data (Adler et al., 2022). There is much overlap between different mental disorders and conventional algorithms are not well suited to process such ambiguous data (Bhugra et al., 2017). For example, a disturbance in sleep quality could be related to various psychiatric disorders (e.g., depression, bipolar disorder, PTSD; not to speak of somatic disorders such as sleep apnea); this challenges the interpretation of data.

Other important points of concern for the use of sensors in mental healthcare are privacy and security (e.g., Drissi et al., 2019). Among the concerns are both unintentional breaches of data and the deliberate transfer or sale of data to third parties (Bauer et al., 2017). Mental health data are highly sensitive and studies show that uncertainty about security is a potential barrier to using technology (Lustgarten et al., 2020). Moreover, the collection of sensor data raises ethical questions regarding privacy, for example concerning data management and the autonomy of users (Gooding & Kariotis, 2021). It is important that therapists are aware of the potential safety risks, and that patients are well informed in order to make a well-advised decision on the use of sensors. Data from an online survey on the willingness to use sensors for mental health purposes showed that patients are generally willing to share their data when they receive valuable feedback related to their health in return and when they feel in control of the data they share (Bessenyei et al., 2021; Boonstra et al., 2018); the latter is not necessarily the case with passive sensing.

Furthermore, there is a range of practical issues regarding the use of sensors. First, the use of sensors may generate technical problems regarding connectivity, storage, power consumption, et cetera (Boonstra et al., 2018; Drissi et al., 2019). Second, the use of sensors comes with expenses, not only to stay up-to-date with technical developments but also due to the legislation on this issue (i.e., privacy and data protection laws and medical device regulations). Third, it is a challenge to keep patients engaged when using sensors in mental healthcare. A user-centered design approach is therefore considered essential during the development of sensors for clinical practice (Boonstra et al., 2018).

Integration of Sensor-Based Technology in Mental Healthcare

In addition to the abovementioned challenges, there is a major challenge regarding the implementation of new interventions and technologies in mental healthcare (Graham et al., 2020). Even though previous studies have introduced frameworks to guide the collection, processing, and analysis of mental health data from start to finish (e.g., Bhugra et al., 2017; Mohr et al., 2017a, b) digital mental health interventions still struggle to find their way from research to clinical practice, resulting in low uptake; this is called the research-to-practice gap (Mohr et al., 2017a). One explanation for this is that the pace at which technologies develop exceeds the pace at which (digital) mental health interventions develop (Bucci et al., 2019). Also, research thus far has primarily focused on the potential of sensors in identifying mental health symptoms, whereas its added value for mental healthcare treatment is underexposed. Another often reported factor is that therapists appear to be reluctant to adjust their treatment methods on the basis of scientific research (Blause et al., 2024; Gyani et al., 2014). However, a clear conceptual basis for embedding technology into mental healthcare that corresponds to values of therapists (e.g., compassion) instead of the organization (e.g., cost-efficiency) could improve their willingness to alter treatment methods (Van Lotringen et al., 2023).

Furthermore, there seems to be a knowledge gap regarding the integration of sensor-based data in mental healthcare. The use of a sensor in therapy means bringing a new source of objective information into a therapeutic process that is traditionally informed by subjective experiences such as introspection and emotions (sometimes augmented with outcome measurements such as routine outcome monitoring). This will undeniably have consequences for the experience of and interaction between therapist and patient.

Regarding the patient experience, the existing concept of a patient journey slightly adapted to the context of sensor-based technology is useful. The patient journey encompasses both the physical and the emotional journeys describing the sequence of steps starting with the patient's awareness that something is not right and all following interactions with healthcare professionals (Devi et al., 2020; McCarthy et al., 2020). For the current study, we define patient journey as the entire trajectory that individuals with mental health conditions follow when using sensors as part of their treatment. This involves the patient's experiences, perceptions of challenges, and benefits associated with sensors as well as the impact on the collaboration with clinicians. The patient journey could include stages such as technology selection, onboarding, monitoring, and data interpretation. The deliberate integration of technology throughout the patient journey empowers patients as active and valuable participants, while also ensuring that the healthcare system becomes responsive to the patient's needs (De Mooij et al., 2022).

We also adapted the existing concept of therapist journey to the context of sensor-based technology. The therapist journey encompasses the journey that therapists follow when being introduced to technology and its implementation in the organization and while working with technology (Jansen, 2022). For the current study, we define "therapist journey" as the experiences and processes that clinicians undergo when incorporating sensors into their therapeutic practices. This involves the therapist's readiness and learning curve regarding integration of technology into sessions, interpretation of sensor data, and its impact on treatment planning. It encompasses the challenges and opportunities therapists encounter as they navigate the use of sensors to enhance their clinical insights, tailor interventions, and monitor patient progress. The therapist journey also includes any adjustments or modifications made to treatment based on the insights provided by the technology.

As described, the concepts of patient journey and therapist journey provide valuable insights into the initial adoption and onboarding processes regarding the use of sensor-based technology in mental healthcare. However, transitioning from adoption to long-term user engagement is crucial for the sustained effectiveness of these technologies (O'Brien & Toms, 2008). Despite the proliferation of mobile applications, achieving sustained user engagement remains challenging (Wei et al., 2020), particularly in populations with mental health issues where motivational barriers are prevalent (Torous et al., 2018). For example, only 14% of individuals who downloaded a popular PTSD Coach application had used the application the day after downloading (Owen et al., 2015). The low engagement levels with mental health apps may be attributed to various factors, including poor usability, lack of user-centered design, privacy concerns, and perceived untrustworthiness (Torous et al., 2018). To address these challenges and to enhance user engagement, several strategies have been proposed. These include providing education on health information technology, involving end users in the design process, integrating clinicians and peers into the app interface, incorporating features for emergency support, implementing frameworks for informed decision-making, and collaborating with professional designers and game developers (Torous et al., 2018). Additionally, Wei et al. (2020) have developed a checklist of design features aimed at optimizing user engagement.

Furthermore, a recent meta-analysis on the psychological treatment of depression showed that therapies are less effective when delivered without direct contact with a therapist (Cuijpers et al., 2023), suggesting that digital interventions are most effective in blended scenarios. However, the proper balance between therapist, patient, and technology remains unclear. It seems important that care and user needs must lead the use of technology, rather than vice versa, but mental healthcare has not yet established models or best practices on how to engage digitally with patients (Bhugra et al., 2017). Lastly, even though studies suggested that the use of technology in mental healthcare does not hinder the establishment of a therapeutic alliance (Berger, 2017; Van Lotringen et al., 2021), clinicians did report concerns on this matter (Gershkovich et al., 2016).

Aim and Research Questions

The aim of the current systematic scoping review is to contribute to the narrowing of the research-to-practice gap by exploring the current state of the research on sensor-based technologies that are to some extent actually integrated in the treatment of patients in mental healthcare. The focus of our review is to provide an overview of the practical integration of sensors in mental healthcare and to gain insight into the process of integrating sensors in clinical practice. This will be done by exploring the following research questions:

1. Which sensor-based technologies have been studied that are integrated in the treatment of patients in mental healthcare?
2. What kind of study designs are used?
3. What are the primary objectives and results (clinical outcomes) of these studies?
4. In what kind of setting did studies take place?
5. Which barriers and facilitators are described regarding the use and integration of sensor-based technology in mental healthcare based on field research?
6. What do these field studies report on the why and how of integrating sensor-based technology in mental healthcare?

Material and Methods

This systematic scoping review was conducted following the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines (Tricco et al., 2018). The main phases of this review were (1) searching for relevant studies; (2) selecting studies based on predefined inclusion criteria; (3) extracting data; and (4) collating, summarizing, and reporting the results. We followed an iterative process, which means that we moved through stages flexibly, repeating steps when needed to ensure the literature was covered in a comprehensive way. Importantly, transparent methods were used for data collection, analysis, and interpretation to ensure reliability and potential for replication.

Eligibility Criteria

Inclusion criteria were (1) studies had to include any kind of sensor-based technology; (2) studies had to include patients who received mental healthcare (any phase of treatment) where the sensor-based technology was to some extent integrated; and (3) full articles containing original research (e.g., no literature review). Exclusion criteria for the current study were (1) articles only accessible in a language other than English or Dutch; (2) articles that were not accessible in full text; and (3) articles published prior to 2015. The reason for this is that technological developments make it likely that older studies are outdated, and the technology described may no longer be available or usable.

Information Sources

A systematic literature search was performed using the databases Scopus, PsycINFO, Web of Science (including PubMed), and IEEE. These databases were chosen because of their focus on social, medical, psychological, and technological topics, with PsycINFO more exclusively focusing on psychological research, Scopus and Web of Science having a broader scope, and IEEE focusing on technological topics. The search was conducted on April 5, 2023.

Search Strategy

First, we checked both the PROSPERO International Prospective Register of Systematic Reviews and Open Science Framework (OSF) for ongoing research considering the integration of sensor-based technology in mental healthcare. No ongoing reviews with the same scope were found in March 2023. As scoping reviews cannot be preregistered in PROSPERO, we preregistered the current study in OSF.

The search string was created in an iterative process, where several initial searches were used to reach the final key concepts. The databases were queried with the following combination of search terms: ("mental disorder" OR "mental health") AND (sensor OR sensing OR wearable OR biocueing OR biosens* OR biofeedback OR "ubiquitous comput*" OR "ambient intellige*" OR "internet of things") AND (psychotherap* OR psycholog* OR psychiatr* OR intervention OR wellbeing OR lifestyle). The key concepts "wellbeing" and "lifestyle" were included in order to find articles that utilized sensors without medical certification, which were therefore not permitted to specifically target mental health. The key concepts were adjusted to fit the different databases.

Selection Process

First, duplicate publications were excluded. Titles and abstracts of the remaining articles were independently screened for eligibility by authors RB and MN. Discrepancies in judgement for eligibility were discussed until agreement was achieved. Subsequently, all selected papers were read in full to check for in- and exclusion criteria by authors RB and MN. Again, discrepancies in judgement for eligibility were discussed until agreement was achieved. The whole selection process was aided using the web application Covidence.

Data Extraction Process

First author RB extracted the data from the included studies. Data extraction was randomly checked by the second author (MN). Disagreements were resolved by consensus. Covidence was used to aid the data extraction process.

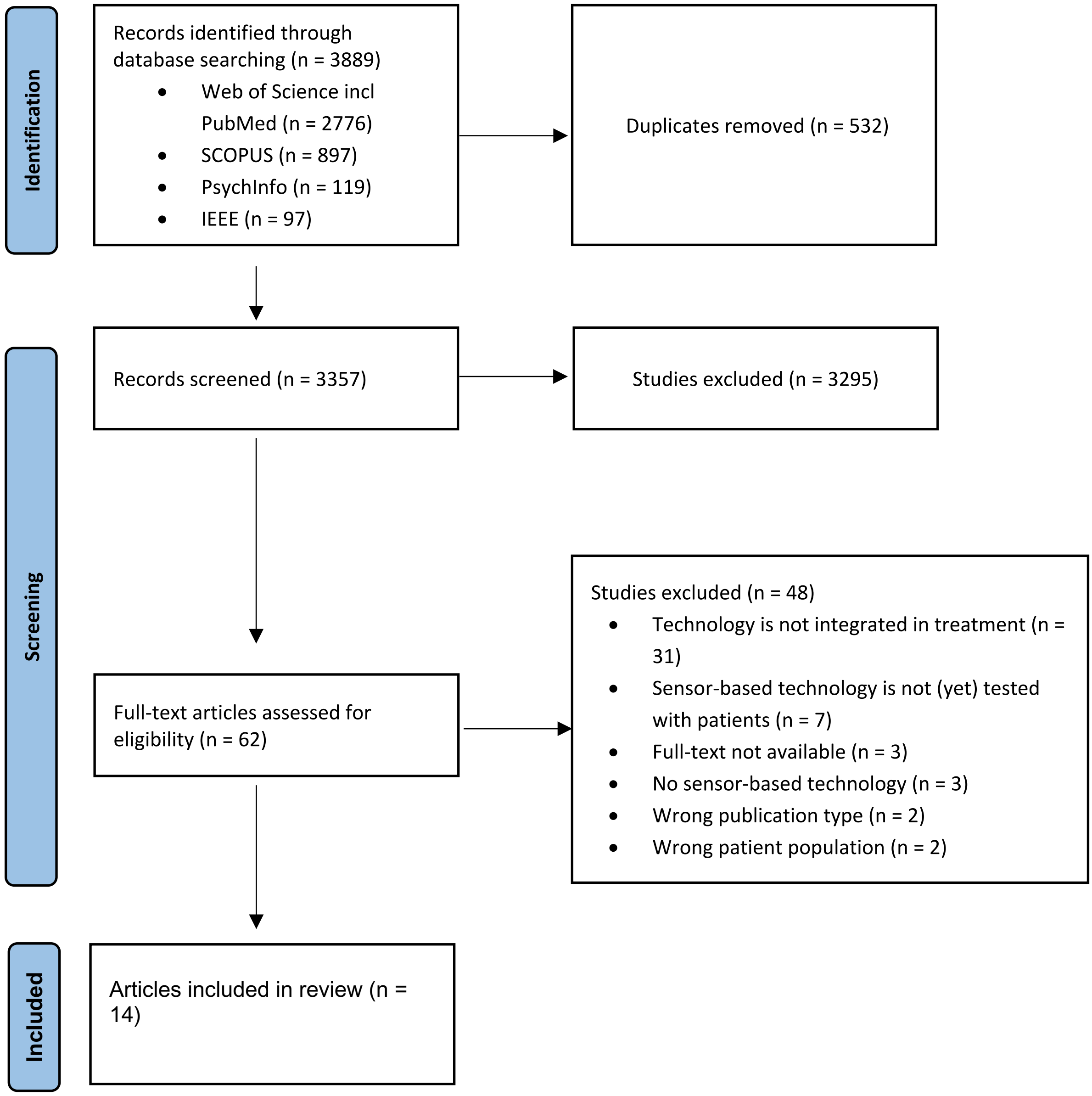

Fig. 1 PRISMA flowchart of the study selection process

Results

Study Selection

The literature search resulted in a total of 3357 unique study records. After title and abstract screening, 62 studies remained. For these papers, full texts were examined in detail to check for in- and exclusion criteria. The predominant reason for exclusion pertained to studies in which the sensor-based technology was used independent of the treatment (instead of being integrated). In the end, 14 studies were included and used for data extraction. An overview of the selection process is visualized in Fig. 1.

Study Characteristics

An overview of the main characteristics of the selected studies is presented in Table 1.

To answer the first research question, we examined the types of sensors that were used in the studies included. This yielded a variety of sensor-based technologies, with some studies using more than one type of sensor. Smartphones (7/14), wrist-worn sensors (5/14), and pulse oximeters (5/14) were used most often, but also a smart infrared camera (1/14) and Bluetooth beacons (1/14) were applied.

Regarding the second research question, we examined the study designs of the studies included. The studies encompassed

Table 1 Description of main characteristics of the selected studies

Study characteristics					Technology characteristics			Therapy characteristics	
Author(s), year	Study design	Sample	Participants *(N; mean age (age range); sex (% male)*	Objective + result	Product	Parameters*	Sensor technologies	Therapeutic approach	Setting
Barrera et al. (2020)	Qualitative study	Adult inpatients from an acute male ward for patients with severe mental health disorders	41; ? (?); 100	Exploring the introduction and impact of sensor-based nurse observations revealed adequate accuracy and enhanced experiences for patients and staff	Oxehealth sensors	HR; PPG; Breathing rate	Infrared camera	Routine nursing observations at night during inpatient care	Blended care
Criswell et al. (2018)	Pilot study	Adult outpatients with PTSD	30; 44 years (20–65); 27	Testing a PTSD treatment module with HRV biofeedback demonstrated its effectiveness in reducing symptoms, not elaborating on the added value of the sensors.	emWave	HRV	Pulse oximeter (finger/earlobe)	CBT + biofeedback	Blended care
Dias et al. (2020)	Randomized experiment (A/B Test)	Adult patients with anxiety receiving psychotherapy in private practice	6; ? (?); ?	Evaluating the usability of iAware and test the effect of gamification on user engagement. iAware was considered useful in anxiety treatment and gamification improved engagement	iAware	HR; pedometer	Smartband; smartphone	CBT	Blended care

Table 1 (continued)

Study characteristics					Technology characteristics			Therapy characteristics	
Author(s), year	Study design	Sample	Participants (*N; mean age (age range); sex (% male)*)	Objective + result	Product	Parameters*	Sensor technologies	Therapeutic approach	Setting
Ducharme et al. (2021)	RCT	Adolescent outpatients with anger dyscontrol	40; 12 (10–17); 72	Assessing the clinical value of incorporating a HRV-game in anger control training (ACT) revealed reduced anger behavior, but not anger feelings	RAGE-Control	HR	Pulse oximeter	CBT + biofeedback	In person
Elsborg et al. (2021)	Pilot study	Adult patients with anxiety	2; 26 (23–29); 0	Exploring the experience of using visual sensor-data for self-reflection on anxiety. Results indicate that visual sensor-data can support patients in confirming anxiety	Empatica E4	EDA	Wrist-worn sensor; desktop application	CBT	Blended care
Huaroto et al. (2022)	Pilot study	Adult patients with anxiety and/or depression	4; ? (?); ?	To validate the usability of WeCare and its effect on events discussed in therapy. WeCare was considered useful and led to an 80% increase of events discussed in therapy	WeCare	HR; Blood oxygenation/BP	smartwatch; smartphone	CBT	Online

Table 1 (continued)

Study characteristics					Technology characteristics			Therapy characteristics	
Author(s), year	Study design	Sample	Participants *(N; mean age (age range); sex (% male)*	Objective + result	Product	Parameters*	Sensor technologies	Therapeutic approach	Setting
Hung et al. (2021)	Pilot study	Patients with mild dementia	10; 69 (64–77); 50	Describing the development of a digital short-term memory training, the study explored usability and learning effects, revealing favorable outcomes and considering the intervention useful	Digital ST memory training	WiFi fingerprint; RSSI location	Smartphone; NFC-tag; Bluetooth 4.0 beacons	Memory training for dementia	Remote
Moss (2019)	Case study	Woman with postpartum depression and dissociation	1, 36 (36), 0	Describing the integration of hypnosis and biofeedback in psychotherapy. Treatment was successful and biofeedback revealed emotions	Unknown	HR; HRV; EDA; PPG; skin temp.; EMG; Respirometer	Pulse oximeter (finger); chest + shoulder sensor + thermometer; EEG	Dynamic psychotherapy + hypnosis + biofeedback	In person
Muramatsu (2021)	Case study	Inpatient with adjustment disorder	1; 20 (20); 0	Describing the use of biofeedback in therapy. The intervention was successful, and biofeedback revealed hidden emotions	Procomp	HR; EDA	Pulse oximeter (finger); SCL sensor (finger)	Sensor-assisted family assessment	In person
Rodriguez-Villa et al. (2020)	Program evaluation	Patients with serious mental illness at Beth Israel Medical Center	n/a	To describe the development and implementation of a digital clinic. Result is a model of a digital clinic	mindLAMP	Accelerometer; gyroscope	Smartphone	?	Blended care

Table 1 (continued)

Study characteristics					Technology characteristics			Therapy characteristics	
Author(s), year	Study design	Sample	Participants *(N; mean age (age range); sex (% male)*	Objective + result	Product	Parameters*	Sensor technologies	Therapeutic approach	Setting
Tsirmpas et al. (2022)	Pilot study	Patients with mild or moderate depression and/or generalized anxiety disorder	48; 38 (18–40); 37	Exploring the feasibility, acceptance, engagement, and potential impact on symptoms of the Feel Program revealed it to be feasible and acceptable, with almost all patients reporting reduced symptoms	Feel Program	HR; HRV; EDA; PPG; skin temperature; accelerometer; gyroscope; magnetometer	Smartphone; wrist-worn sensor	CBT; mindfulness; positive psychology; emotion journaling	Online
Van Doorn et al. (2022)	Pilot study	Adolescents (16–25 years) with emerging mental health complaints	8; 22 (16–25); 0	To explore the usability, feasibility, and potential effect of biocueing in addition to a moderated digital platform. Results show moderate usability and small positive effects on emotional awareness	Sense-it	HR	Smartwatch; smartphone	Moderated Online Social Therapy (MOST+)	Online
Wahle et al. (2016)	Pilot study	Adult outpatients with clinical depression	36; ? (20–57); ?	Exploring depression symptom detection through sensor data and context-sensitive intervention delivery, the study found accurate depression detection and reduced self-reported symptom severity	Mobile Sensing and Support (MOSS)	GPS; WiFi fingerprint; WiFi-based location logging; phone usage	Smartphone	CBT	Online

Table 1 (continued)

Study characteristics					Technology characteristics			Therapy characteristics	
Author(s), year	Study design	Sample	Participants (N; *mean age (age range); sex (% male)*)	Objective + result	Product	Parameters*	Sensor technologies	Therapeutic approach	Setting
Wang et al. (2016)	RCT	Adult victims of torture and war in Kosovo	28; 48 (?); 55	Testing a multidisciplinary intervention's impact on mental, emotional, and physical health revealed promising overall results, not elaborating on the added value of the sensors	emWave	HRV; breathing rhythm	Pulse oximeter (finger/earlobe)	CBT (prolonged exposure) + bio-feedback	In person

**HR* Heart Rate, *HRV* Heart Rate Variability, *PPG* Photoplethysmography, *EDA* Electrodermal Activity, *BP* Blood pressure, *EMG* Electromyography

a diverse range of study designs. It is noteworthy that all were conducted very recently (since 2016) and that half of them (7/14) were pilot studies, whereas only 3/14 studies were experimental designs. The other study designs were case studies (2/14), qualitative study (1/14), and program evaluation (1/14).

To answer the third research question, we examined the primary objectives and results of the studies included. Most studies (9/14) aimed to examine or explore the effect of a technology-aided intervention on symptoms, such as the effect of visualizing sensor-data on anxiety treatment (Elsborg et al., 2021), with all of them reporting (small) positive effects. Other objectives were to describe the development and integration of sensor-based technology (5/14), and to examine usability, feasibility, and/or acceptance of the technology (5/14), with all of them reporting moderate to high usability. Both case studies (2/14) reported that biofeedback helped to reveal hidden emotions during psychotherapy.

Regarding the fourth research question, we examined the setting where therapy took place. It is seen that in 4/14 studies sensors were used during in-person sessions, in 5/14 studies blended care was applied, and in 5/14 studies there was online or remote contact between patient and therapist.

Barriers and Facilitators

Table 2 gives a detailed overview of barriers and facilitators regarding the use and integration of sensors as identified across the selected studies. This information was used to answer the fifth research question.

Most of the included studies (9/14) did not specifically report on barriers for the *use* of sensors in mental healthcare. The remaining studies ($n = 5$) identified two main barriers: technical problems (4/5, e.g., problems with battery life), and issues regarding the design of the sensor (3/5).

Ten studies reported on barriers for the *integration* of sensors in clinical practice. The majority of these studies (8/10) emphasized the preliminary nature of research, underscoring the need for more robust evaluation with larger sample sizes to determine clinical efficacy and identify patient populations that could benefit from sensors. Additional barriers encompassed a diverse spectrum of concerns demanding attention for successful implementation, such as addressing legal hurdles for sensor use in clinical practice (1/10), the need for technical assistance (1/10), and challenges regarding the evaluation process after technology implementation (1/10).

Half of the included studies (7/14) did not report on facilitators for the *use* of sensors. The remaining studies ($n = 7$) identified two main facilitators: a favorable user experience (4/7), and the presence of well-functioning and easy-to-use technology (3/7). Additionally, one study pointed to

Table 2 Description of barriers and facilitators regarding the use and integration of sensor-based technology

Author(s), year	Barriers for using sensor-based technology	Barriers for integrating sensor-based technology in clinical practice	Facilitators for using sensor-based technology	Facilitators for integrating sensor-based technology in clinical practice
Barrera et al. (2020)	-	• Use of camera observation could interfere with privacy of patients • Research is preliminary	• Sensors were easy to use • System functioned well	• Sensors had a positive impact on inpatients by reducing sleep disturbance and improving privacy and on staff by saving time and reducing aggression
Criswell et al. (2018)	-	-	-	• Blended care was appreciated by patients
Dias et al. (2020)	• Configuration between smartband and smartphone needs improvement • False positives need to be reduced	• Laws and regulation do not always allow the use of sensor-based technology during treatment • Research is preliminary	-	• Most patients found the sensor-based anxiety reports useful • The use of iAware could enable more effective treatment
Ducharme et al. (2021)	-	• Research is preliminary • Adverse effects were not systematically assessed	-	• Augmenting ACT with RAGE-Control enhanced patient's control of anger expression • Incorporating games into therapy may improve engagement
Elsborg et al. (2021)	• The wristband was too large • The wrist band drew attention from others in their surrounding	• Being monitored constantly was uncomfortable for one patient and resulted in being overly focused on anxiety • Research is preliminary	-	• Visualization of physical reactions can be reassuring and comforting • Integrating visualizations in CBT could bring insight in anxiety triggers and improve crisis plans • Constant monitoring could lead to increased self-awareness
Huaroto et al. (2022)	-	-	• Usability scores were high	• Time required to measure HR and blood oxygenation was reduced • More events of anxiety were discussed in therapy when using the sensor-based technology
Hung et al. (2021)	• Positioning accuracy needs improvement	• More training items are needed • SUS scores were average to low indicating that for some the system was not usable • Technical assistance is needed • Research is preliminary	• System is easy to operate • Sufficient satisfaction scores	• The use of digital tools was acceptable for most patients • The system allows systematic monitoring and training outside the hospital
Moss (2019)	-	-	-	• Study reports added value of biofeedback on psychotherapy
Muramatsu (2021)	-	-	-	• Visualized physiological signals revealed emotional responses • Biofeedback helped to shift the focus from individual to family

Table 2 (continued)

Author(s), year	Barriers for using sensor-based technology	Barriers for integrating sensor-based technology in clinical practice	Facilitators for using sensor-based technology	Facilitators for integrating sensor-based technology in clinical practice
Rodriguez-Villa et al. (2020)	-	• Maintaining updated technology is a challenge • Executing effective evaluation protocols • Ensuring ongoing quality improvement efforts	• App can be customized at every visit to be relevant to each patient's illness and recovery • Patient data can be easily shared with clinicians	• Authors introduced a "Digital Navigator" who offers technical support and gathers feedback • Authors designed a program to develop skills for accessing and utilizing digital health
Tsirmpas et al. (2022)	• Battery life should be improved • Patients would like the option to visualize the collected data • Sensor design can be improved	• Research is preliminary	• Application is easy to use • Technical difficulties were scarce	• Overall patient satisfaction levels and patient engagement are high • Sensors accurately identified emotional events "in the wild" • Physiological data is well-integrated in treatment
Van Doorn et al. (2022)	• Technical problems and design problems with the smartwatch	• Accessibility, engagement, and integration of smartwatch and MOST+ should be improved	• Acceptable usability scores	• Smartwatch helped to improve emotional awareness and could increase coping with emotions
Wahle et al. (2016)	-	• Research is preliminary	-	• Study showed improvement of depression levels • Sensors could detect clinically relevant levels of depression
Wang et al. (2016)	-	• Research is preliminary • Limited effect of the intervention	• Attendance rates were high	-

Table 3 Overview of the why and how of integrating sensor-based technology in mental healthcare

Author(s), year	Did article report on… the why of using sensors in clinical practice?	… therapeutic alliance?	…patient journey?	…therapist journey	…training of clients?	… training of therapists?
Barrera et al. (2020)	Yes	No	Limited	Limited	n/a	Limited
Criswell et al. (2018)	No	No	Limited	No	No	No
Dias et al. (2020)	Yes	No	Limited	Limited	No	No
Ducharme et al. (2021)	Yes	No	Limited	Limited	No	Limited
Elsborg et al. (2021)	Yes	No	Limited	Limited	Limited	No
Huaroto et al. (2022)	Yes	No	Limited	Limited	No	No
Hung et al. (2021)	Yes	No	Limited	Limited	No	No
Moss (2019)	Yes	No	Limited	Limited	No	No
Muramatsu (2021)	No	No	Limited	Limited	No	No
Rodriguez-Villa et al. (2020)	Yes	No	Yes	Yes	Yes	Yes
Tsirmpas et al. (2022)	Yes	No	Limited	Limited	No	No
Van Doorn et al. (2022)	Yes	No	Limited	Limited	No	No
Wahle et al. (2016)	Yes	No	Limited	No	No	No
Wang et al. (2016)	No	No	Limited	No	No	No

the value of customizability of the technology to the needs of the patient, while another study identified the ability to securely share patient data with fellow clinicians as a facilitative factor.

All but one of the studies (13/14) provided insights into the facilitators for *integrating* sensors in mental healthcare. A majority of these studies (8/13) emphasized the positive effect of sensors on treatment outcomes (e.g., improved emotional awareness). Also, several studies specifically mentioned positive outcomes for patients (3/13, e.g., reduced sleep disturbance), or for clinicians (2/13, e.g., reduced incidents of aggression). Furthermore, some studies (4/13) reported that the implementation of sensors was well accepted (or even appreciated) by patients, and 2/13 studies indicated that treatment engagement was improved by using sensors. A key finding is the importance of providing training to develop the required technical skills for both patients and staff. Additionally, the significance of adequate technical support during the utilization of technology emerged as a critical factor.

The Why and How of Integrating Sensor-Based Technology in Mental Healthcare

Table 3 provides an overview of whether articles reported on factors related to the why and how of integrating sensors in mental healthcare. This information was used to answer the sixth research question. Regarding the why, studies were examined for their rationale regarding the use of sensor-based technology. Regarding the how, studies were searched for information about the therapeutic alliance, patient journey, therapist journey, training of clients, and training of therapists.

Most of the studies (11/14) reported some kind of rationale for the integration of sensors in their specific patient population. In these studies ($n=11$), the most frequently mentioned rationale is the premise that sensors will improve treatment effect (9/11). Other reasons were to improve patient engagement (2/11), to gain a more objective diagnosis (1/11), and to improve access to mental healthcare (1/11).

Interestingly, none of the studies elaborated on the effect of the integration of sensors on the therapeutic alliance.

All studies reported on aspects of the patient journey, but the provided information was mostly scarce and focused on the actual use of the technology instead of its indication or its impact on the interaction between patient and therapist. In most studies (9/14) patients received direct feedback based on the sensor-data, for example in the form of a direct data visualization. In the other studies (5/14) patients did not receive direct feedback based on the sensor data. In two of these cases, patients did not receive any feedback on the sensor data; in the remaining studies patients received feedback at a later time, e.g., during a therapy session. Only 1/14 studies extensively reported on the impact of technology on the collaboration between patient and therapist, highlighting shared decision making. The same study is unique in reporting on the constant ability to customize the technology according to the patient's needs and on how they provide thorough technical support. None of the studies reported that patients were informed on how data were stored.

Most studies (11/14) reported on the therapist journey to some extent, but again, the provided information was mostly scarce. Of these studies ($n=11$) none extensively reported on the indication for sensor-based technology, i.e., when (in what treatment phase) and for whom. Some studies (4/11) did mention how the technology was introduced, but these descriptions are not detailed. In some studies (3/11) protocols were developed in which the impact of the sensor data on treatment approach is described. Others (3/11) only mention that the therapist used the data in treatment, but do not elaborate on how. One study developed guidelines for how to communicate with patients outside of sessions, including policies for emergency situations. Lastly, 2/11 studies reported the option to stop using the technology in the case of adverse effects, suggesting that they actively evaluate the use and impact of the technology during treatment.

Only one study (1/14) extensively reported on the training of both patients and therapists. These authors developed a manual to guide digital skill-building for patients and offered specialized training for clinicians to teach digital skills, competencies, and confidences. Furthermore, one study explained patient introduction to the technology, while two studies briefly covered therapist introduction.

Discussion

The aim of the current review was to provide an overview of the nature of the practical integration of sensor-based technology in mental healthcare, to explore barriers and facilitators involved, and to explore the why and how of integrating sensors in clinical practice. Through a systematic literature search, 14 relevant studies were included.

With regard to the nature of the practical integration of sensors in mental healthcare, we examined the types of sensors used, the study designs, the primary objectives and results, and the setting in which sensors were integrated. The included studies used a variety of sensors, mainly smartphones, wrist-worn sensors, and pulse oximeters. Regarding the study designs, we found that most studies were pilot studies and only few used experimental designs. Importantly, the relatively low number of studies on this topic, along with the types of study designs employed, highlights a significant gap in research and the integration of sensor technology into treatment protocols and the mental healthcare system in general. Surprisingly, this suggests that the field is still in the early stages of exploring sensor-based technology for mental healthcare, primarily focusing on assessing initial effectiveness and usability. Consequently, sensor-based technologies mostly lack the well-designed and structural embedding within treatment (protocols), economic renumeration, and governance which would be an indication of more robust technological development, implementation, and evaluation (Arthur, 2009). This aligns with previous statements that sensors struggle to make their way to routine clinical practice (Mohr et al., 2017a, b). With regard to the setting in which sensors were integrated, we found an almost even distribution between in-person sessions, blended care, and online/remote contact between patient and therapist. The relatively large share of online/remote contact is striking when you consider recent findings that digital interventions are most effective in blended scenarios (Cuijpers et al., 2023). All studies with online/remote contact between patient and therapist were pilot studies focusing on feasibility/usability. Nevertheless, most of these studies did report preliminary positive effects on symptom reduction.

Remarkably, most studies did not report systematically on barriers and facilitators for using and integrating sensors in mental healthcare. The main barrier for integrating sensors was considered the preliminary state of research in this field, both regarding the clinical added value of using sensors and regarding how to effectively integrate the technology into treatment. Additional barriers for the use and integration of sensor-based technology are predominantly practical in nature, encompassing technical challenges, design issues, and legal hurdles. Regarding the facilitators for using and integrating sensors in mental healthcare, a favorable user experience and the presence of well-functioning and easy-to-use technology were most often reported. And although preliminary, most studies did report positive effects on treatment outcomes, for example by reducing symptoms of depression (Wahle et al., 2016).

Interestingly, the barriers and facilitators that were mentioned by the studies mainly concerned the technology and its effect. However, innovation and implementation processes can be divided in four stages (dissemination, adoption, implementation, and continuation) each of which are affected by various determinants: (1) the socio-political context (rules, legislation); (2) organization characteristics (decision-making process); (3) user characteristics (knowledge, skills); and (4) innovation characteristics, in this case the technology (complexity, advantage; Fleuren et al., 2004). For future research concerning the implementation of sensor-based technology, it is crucial to expand the scope from the technology itself to the other determinants as the intended user is not isolated from an organization which is in turn part of a larger environment (Fleuren et al., 2004). Furthermore, to effectively integrate sensors into mental healthcare, substantial investments from major corporations are essential, given their significant influence in technology development. Therefore, to make the next step, it is necessary that these companies would recognize and prioritize the importance of such integration efforts (Connors, 2024; McGinty et al., 2024).

The sixth research question concerned the why and how of integrating sensors in mental healthcare. With regard to the "why," most studies reported some kind of rationale for using sensors, mostly the premise that the technology could have a positive effect on the treatment outcomes. When delving into the "how" of integrating sensor-based technology, a key finding is that information on the patient journey and therapist journey is very limited. Importantly, the indication for using sensors remains unclear: studies did not report specific ideas on when (in what treatment stage) technology could be of interest for whom. While the potential of sensors for clinical practice is recognized, the therapeutic conditions under which it should be utilized are not well-defined. Clarity on this matter is crucial for the integration of sensors, mirroring the practice of providing indications and contraindications when introducing a new treatment protocol (e.g., Keijsers et al., 2017). Furthermore, the impact of integrating sensors on the collaboration between patient and therapist has not been evaluated: the included studies did not report on its impact on the therapeutic alliance, and it is not clear how sensors should and could affect the treatment approach. Lastly, in most of the examined studies, patients had minimal involvement in decision-making regarding the use of sensors, and they were often not adequately informed or engaged in data management. Only one of the included studies comprehensively addressed most of these issues (Rodriguez-Villa et al., 2020). These authors emphasized the importance of shared decision making and of the customization of technology to meet individual's needs. Furthermore, this was the only study that extensively reported on the training and technical support needed to develop the required technical skills for both patients and staff by introducing a third person in the treatment. This so-called Digital Navigator is a dedicated person who provided continuous technical support during treatment, assisting both patients and staff with technical issues and technology customizations.

For future research, it is recommended to use a framework to systematically examine implementation problems (Kip et al., 2024), for example the Theoretical Domains Framework (TDF; Cane et al., 2012). This framework has previously been used to examine the implementation of virtual reality (VR; Glegg & Levac, 2018), which led to clear recommendations to facilitate the implementation of VR in mental healthcare and to support systematic evaluation of implementation efforts. Their recommendations were (1) to enhance collaboration between engineers, clinicians, managers, and patients; (2) to ensure that interventions to improve integration are system and context specific; and (3) to optimize the effectiveness of technology by using an evidence-based approach. These recommendations can easily be translated to the integration of sensor-based technology as indicated by our current findings.

The findings of our review should be considered within the context of several limitations. First, although broad search terms were used to ensure a comprehensive literature search, the relatively small number of field studies may be perceived as a limitation. Although this is in line with the exploratory nature of a scoping review, it implies that conclusions drawn from this limited set of studies should be regarded as preliminary. Second, there is significant heterogeneity among included studies in terms of methodology, quality, populations, and interventions. The decision to refrain from preselecting on these aspects was intentional, to present a complete overview of the existing literature. However, this affects the ability to draw generalized conclusions. Moreover, the decision to include studies published from 2015 onwards was motivated by the rapidly evolving field of technology. While this choice allowed us to capture recent developments, it also implies that the current findings may become outdated relatively quick. Lastly, post hoc we examined the countries where the included studies took place. Most studies took place in Europe or North America and only few in South America or Asia. We do not know whether this reflects the true situation or that this result is biased due to our selection on studies published in English (or Dutch). A priori, we would have expected a larger share of studies from Asia (Japan, China), but based on the Global Innovation Index (2023), our results could well reflect the true situation.

To conclude, this scoping review provided a comprehensive overview of the current literature on field studies using sensor-based technology in mental healthcare. The existing body of research has primarily focused on the crucial aspects of acceptance and feasibility, while some studies have started to explore the impact of sensors on clinical outcomes. From these studies we can conclude that sensor-based technologies are sufficiently accepted and feasible. Moreover, the preliminary evidence suggests that sensors are promising for enhancing clinical outcomes. Now it is time for a next phase, aimed at the deliberate, systematic incorporation of sensors in mental healthcare treatment. This next phase asks for a multifaceted approach consisting of (1) embedding sensors in treatment protocols in cocreation with patients and clinicians, (2) examining the feasibility of these interventions together with small-scale evidence studies, and (3) systematically examine the implementation of sensors in clinical practice using existing frameworks for technology implementation. By employing established frameworks for technology implementation, such as previously mentioned, we can pave the way for a more profound and therapeutic integration of sensor-based technology into mental healthcare.

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Declarations

Ethics Approval Not applicable for our review study.

Consent to Participate Not applicable for our review study.

Consent to Publish All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Rianne Bosch and Matthijs Noordzij. The first draft of the manuscript was written by Rianne Bosch and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript and consent with publication.

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