International Journal of Medical Informatics 190 (2024) 105560

Contents lists available at ScienceDirect

International Journal of Medical Informatics

journal homepage: www.elsevier.com/locate/ijmedinf

Review article

# Smartwatch interventions in healthcare: A systematic review of the literature

Andreas Triantafyllidis [a,*], Haridimos Kondylakis [b], Dimitrios Katehakis [b], Angelina Kouroubali [b], Anastasios Alexiadis [a], Sofia Segkouli [a], Konstantinos Votis [a], Dimitrios Tzovaras [a]

[a] *Information Technologies Institute, Centre for Research and Technology Hellas, Thessaloniki, Greece*
[b] *Institute of Computer Science, Foundation for Research and Technology Hellas, Heraklion, Greece*

ARTICLE INFO

*Keywords:*
Smartwatch
Digital health
Literature review
Interventions

ABSTRACT

*Objective:* The use of smartwatches has attracted considerable interest in developing smart digital health interventions and improving health and well-being during the past few years. This work presents a systematic review of the literature on smartwatch interventions in healthcare. The main characteristics and individual health-related outcomes of smartwatch interventions within research studies are illustrated, in order to acquire evidence of their benefit and value in patient care.

*Methods:* A literature search in the bibliographic databases of PubMed and Scopus was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, in order to identify research studies incorporating smartwatch interventions. The studies were grouped according to the intervention's target disease, main smartwatch features, study design, target age and number of participants, follow-up duration, and outcome measures.

*Results:* The literature search identified 13 interventions incorporating smartwatches within research studies with people of middle and older age. The interventions targeted different conditions: cardiovascular diseases, diabetes, depression, stress and anxiety, metastatic gastrointestinal cancer and breast cancer, knee arthroplasty, chronic stroke, and allergic rhinitis. The majority of the studies (76%) were randomized controlled trials. The most used smartwatch was the Apple Watch utilized in 4 interventions (31%). Positive outcomes for smartwatch interventions concerned foot ulcer recurrence, severity of symptoms of depression, utilization of healthcare resources, lifestyle changes, functional assessment and shoulder range of motion, medication adherence, unplanned hospital readmissions, atrial fibrillation diagnosis, adherence to self-monitoring, and goal attainment for emotion regulation. Challenges in using smartwatches included frequency of charging, availability of Internet and synchronization with a mobile app, the burden of using a smartphone in addition to a patient's regular phone, and data quality.

*Conclusion:* The results of this review indicate the potential of smartwatches to bring positive health-related outcomes for patients. Considering the low number of studies identified in this review along with their moderate quality, we implore the research community to carry out additional studies in intervention settings to show the utility of smartwatches in clinical contexts.

## 1. Introduction

The interest in using wearable devices to manage health has shown rapid growth [1,2]. Smartwatches represent an increasingly available category of wearable devices that can empower individuals to take charge of their well-being and improve their health right from their wrists [3]. The smartwatch is a general-purpose networked computer that primarily functions as a mobile phone extension, supporting the monitoring of physical activity and other health-related parameters such as heart rate, blood oxygen saturation, energy expenditure, sleep quality, etc., through the use of an array of sensors, and the delivery of prompt notifications to the user [4]. Modern smartwatches most often

* Corresponding author at: Information Technologies Institute, Centre for Research and Technology Hellas, Thessaloniki 57001, Greece.
*E-mail address:* atriand@iti.gr (A. Triantafyllidis).

https://doi.org/10.1016/j.ijmedinf.2024.105560
Received 22 February 2024; Received in revised form 25 June 2024; Accepted 16 July 2024
Available online 18 July 2024

include touch screens [5], and enable the collection of patient-reported outcomes [6]. Furthermore, they offer cutting-edge capabilities for enhanced user interactions, e.g., through the use of apps [7], thereby providing more advanced features than other consumer wearable devices [8].

The adoption of smartwatches for healthcare purposes emerges as a promising approach to support patient self-management or remote medical management, mainly because of their capability to monitor several health parameters and detect health deterioration in free-living environments around the clock. The acceptability, usability, and potential of smartwatches in improving health and well-being have been explored in a number of previous studies [9–13].

Despite the increasing demand for smartwatches by consumers [14], reviews of their effectiveness on health outcomes in research studies, have been remarkably limited. To the authors' knowledge, the most relevant comprehensive systematic reviews of the literature in this field are dated back to 2016 [3,15]. Other previous reviews have focused more broadly on wearable devices [16,17] and their use in specific diseases such as cardiovascular disease [18], diabetes [19], depression [20], or ordinary trackers for physical activity promotion [21,22].

Considering the widespread adoption and virtue of smartwatches in healthcare, an up-to-date systematic review of the literature is required. To this end, the primary objective of this review is to synthesize the available evidence on smartwatch interventions utilized within research studies and evaluate their effectiveness on individual health-related outcomes. The main features of smartwatch interventions and their outcomes are presented, in order to acquire evidence of the benefit of smartwatches in clinical applications, and further improve the understanding of the research community on opportunities and challenges related to their use and adoption.

## 2. Methodology

The authors searched the widely-used bibliographic databases of Scopus and PubMed to identify clinical research studies published till April 2023, utilizing smartwatch interventions. The inclusion criteria for study selection were the following: (a) the study should target one or more diseases, (b) the use of a smartwatch should be described as part of the intervention, (c) quantitative health outcomes of a clinical trial should be presented, and (d) the paper describing the study, must have been written in English. Ongoing studies, case reports, simulation studies, surveys or reviews, qualitative studies, studies describing protocols, studies with non-human samples, and studies targeting exclusively feasibility, usability, or acceptance of the intervention were excluded. We also excluded studies that reported the use of a fitness device rather than a smartwatch. The above distinction was based on information retrieved from the website of the manufacturer of the wearable device. There was no limit placed on the target population or the disease outcome of interest.

Searches of the electronic databases were conducted in April 2023, and the following terms were used for the literature search within the title, abstract, and keywords of the manuscripts: *("smartwatch" OR "smart watch") AND ("health" OR "healthcare" OR "intervention")*. The Mendeley© bibliography management software [23] was used to manage all references. Duplicates were removed, and a spreadsheet was created with extracted information from each article regarding the authors, title, abstract, and digital object identifier, and was shared among the authors who conducted the review (AT, HK, DK, AK, TA, SS).

The article screening procedure involved two rounds. During the first screening round, pairs of two authors independently screened the papers, in order to eliminate possible errors or bias in the selection process. All abstracts of the found articles were assessed for their eligibility according to the inclusion and exclusion criteria. During the second screening round, the final papers for inclusion in the review were selected by pairs of two reviewers after reading the full manuscripts of the articles found to be eligible in the first round. Discrepancies between reviewers were resolved by consensus. Inter-rater reliability statistics were not used. The following data elements were extracted from the final papers and summarized in tables: Study target disease, smartwatch model, intervention target, devices used in addition to smartwatch, main features of intervention, study design, number of participants, age of participants, study follow-up duration, outcome measures, and whether authors reported statistically significant ($p < 0.05$) or clinically meaningful outcomes.

In order to evaluate the methodological quality of the studies, we used the Effective Public Health Practice Project (EPHPP) tool, which is based on the six quality criteria for participant selection bias, study design, handling of confounders, participant and researcher blinding, data collection methods, and withdrawals or dropouts. We utilized EPHPP because it has a track record of reliability and is frequently used in review studies [24]. According to the tool's instructions, a grade of weak, moderate, or strong is assigned to each quality criterion. When no weak ratings have been discovered, a global rating of strong is applied, a global rating of moderate is applied when one weak rating has been discovered, and a global rating of weak is applied when two or more poor ratings have been discovered. The systematic review was conducted following the PRISMA guidelines [25].

## 3. Results

### 3.1. Literature search outcomes

In total, 1099 records were obtained from Scopus and 353 records from PubMed (Fig. 1). The retrieved records were imported into the Mendeley© bibliography management software, and 327 duplicates were removed. The abstracts of the remaining 1125 articles were screened according to our inclusion and exclusion criteria, from which we identified 19 eligible articles. The reviewers read the full text of those 19 manuscripts and agreed to include 13 eligible manuscripts [26–38]. The included studies were published from 2018 to 2023. Reasons for the exclusion of the manuscripts can be found in Fig. 1. Furthermore, we identified 8 ongoing clinical trials after searching the database of clinicaltrials.gov and setting the filters for interventional studies and active studies (either not yet recruiting, recruiting, or active and enrolling by invitation) according to our inclusion and exclusion criteria. Further details about the ongoing trials which were excluded from this review, can be found in Appendix A, Table A1.

### 3.2. Quality assessment

According to the EPHPP criteria, the methodological quality was found to be strong for 2 studies (15 %) [30,32], moderate for 7 studies (54 %) [26,32,34–38], and weak for 4 studies.

(31 %) [27–30] (Table 1). The studies with weak ratings were associated mostly with insufficient description of the validity and reliability of data collection methods, many withdrawals or dropouts of participants, no blinding of researchers or participants, and insufficient dealing with confounding. In terms of study design, 10 studies (76 %) were randomized controlled trials, and 3 studies (23 %) employed a non-randomized design.

### 3.3. Intervention target and technological devices

The 13 studies utilized smartwatch interventions in everyday life to support health and well-being, with the following targets (Table 2 and Fig. 2): (a) 4 interventions (31 %) targeted cardiovascular diseases including atrial fibrillation and acute myocardial infarction [29,33,34,37], (b) 2 interventions (15 %) targeted diabetes [26,36], (c) 2 interventions (15 %) targeted cancer [32,35], and (d) 2 interventions (15 %) targeted mental health disorders [27,38]. Other interventions targeted knee arthroplasty [28], chronic stroke [30], and allergic rhinitis [31]. The main reason for using smartwatches in the included

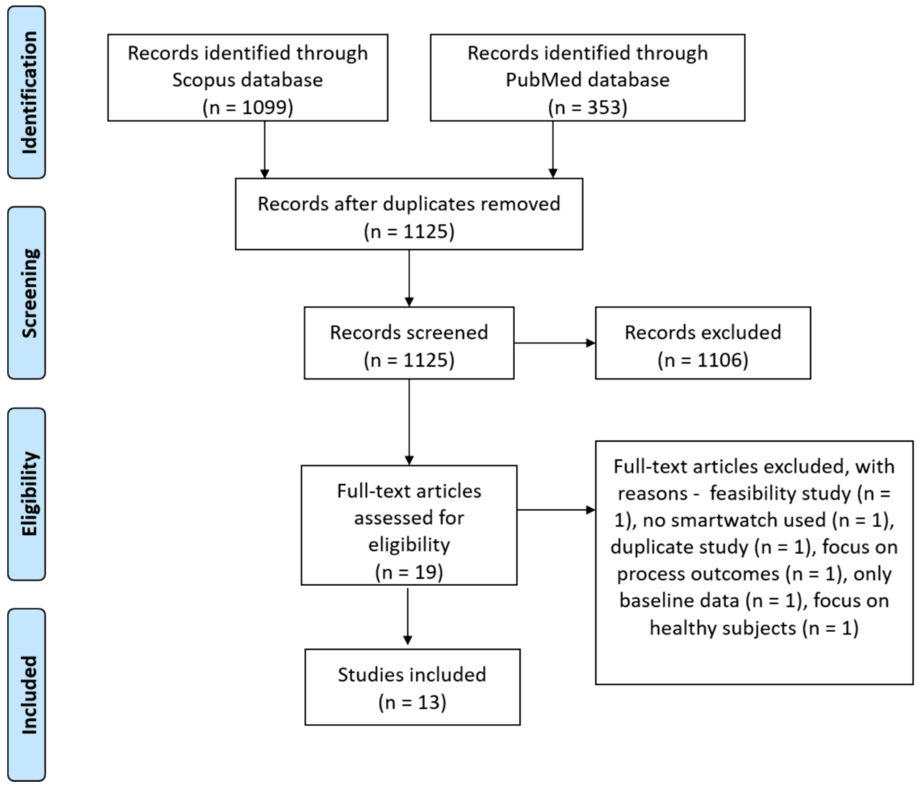


**Fig. 1.** PRISMA flow diagram for study inclusion.

**Table 1**
Quality assessment (W: Weak, M: Moderate, S: Strong) of included studies based on the EPHPP criteria.

| Study | EPHPP Criteria | | | | | | Global Rating |
|---|---|---|---|---|---|---|---|
| | **Selection Bias** | **Study Design** | **Confounders** | **Blinding** | **Data Collection** | **Withrawals – Dropouts** | |
| Abbott et al [25] | M | S | M | M | M | W | M |
| Aguilar-Latorre et al [26] | M | S | W | M | W | M | W |
| Alexander et al [27] | M | S | M | M | W | W | W |
| Broers et al [28] | W | S | W | W | M | S | W |
| Chae et al [29] | M | W | S | W | M | W | W |
| Li et al [30] | M | S | S | M | M | S | S |
| Low et al [31] | M | S | M | W | M | S | M |
| Marvel et al [32] | S | S | M | M | M | S | S |
| Perez et al [33] | M | M | M | M | M | W | M |
| Pope et al [34] | M | S | S | W | M | M | M |
| Timurtas et al [35] | M | S | S | M | W | S | M |
| Trinquart et al [36] | S | S | S | M | M | W | M |
| Wallace et al [37] | M | S | M | W | M | S | M |

studies was their capability for automated health-related data collection [27–31,33–37], and notification triggering [26,32,38].

In terms of technological devices used in the included studies, the Apple Watch was used in 4 studies [28,33,34,37] (31 %), Fitbit [29,32] and LG [30,38] smartwatches were used each in 2 studies (15 %), whereas other studies employed other devices such as Polar M400 [35] and Ticwatch E [36]. Participants in all studies were provided with a smartwatch by the research team, except only one study, in which participants were required to possess their own smartwatch [34]. In the vast majority of the interventions, i.e., 9 out of 13 (69 %), a smartphone was used in conjunction with a smartwatch.

### 3.4. Main intervention features

The main feature of the smartwatch interventions was the delivery of notifications or reminders and alerts to the user, found in 9 out of 13 interventions (69 %). In 6 interventions, the notifications were delivered via smartwatch, and in 3 interventions, the notifications were sent through a companion smartphone app. More specifically, Abbot et al [26], utilized smartwatch audiovisual alerts when aberrant pressures on the foot were detected. Broers et al [29], used smartphone messages for health behavior change based on data derived from several health monitoring devices including a smartwatch. Li et al [31] used medication SMS reminders when the smartwatch detected no medication compliance. Low et al [32] delivered smartwatch messages for physical activity promotion. Marvel et al [33] used medication reminders delivered to both the smartwatch and the smartphone. Perez et al [34] utilized smartwatch irregular pulse notifications. Timurtas et al [36] used smartwatch notifications to push exercise reminders. Trinquart et al [37] used personalization schemes to deliver smartphone notifications to boost adherence with taking vital sign measurements. Finally, Wallace et al [38] used a smartwatch app to provide instructions and reminders to do deep breathing exercises for stress management. Other features of the smartwatch interventions included measurement and

**Table 2**
Characteristics of smartwatch interventions in included studies.

| Study | Target Disease | Smartwatch Model | Intervention Target | Additional Devices | Main Features |
|---|---|---|---|---|---|
| Abbott et al [26] | Diabetes | SurroSense Rx | Reduction of diabetic foot ulcer recurrence | Insole system | Audiovisual alerts and offloading instructions upon detection of aberrant pressures |
| Aguilar-Latorre et al [27] | Depression | N/A | Health promotion and lifestyle modification | – | Measurement of daily minutes walked and sleep patterns, weekly education sessions |
| Alexander et al [28] | Total knee arthroplasty | Apple Watch | Rehabilitation and monitoring | Smartphone | Exercise program at home |
| Broers et al [29] | Cardiovascular diseases | Fitbit smartwatch | Health promotion and lifestyle modification | Smartphone, sleep tracker, home monitoring device, blood pressure monitor, weight scale | Behavior change program based on data-driven messages |
| Chae et al [30] | Chronic stroke | LG W270 | Rehabilitation and monitoring | Smartphone | Exercise program at home |
| Li et al [31] | Allergic rhinitis | Smartwatch with camera and AI, InHandPlus, Inc. | Improvement of medication adherence and symptom control | – | Detection of medication intake, symptom tracker, reminders |
| Low et al [32] | Metastatic gastrointestinal cancer | Fitbit Versa | Detection and disruption of prolonged sedentary behavior | Smartphone | Daily ratings of symptom severity, prompts for physical activity promotion |
| Marvel et al [33] | Acute myocardial infarction | Apple Watch | Reduction of hospital readmissions | Smartphone, blood pressure monitor | Medication reminders, vital sign and activity tracking, education, and outpatient care coordination |
| Perez et al [34] | Atrial fibrillation | Apple Watch | Identification of atrial fibrillation during typical use of wearables | Smartphone (iPhone) | Irregular pulse notification |
| Pope et al [35] | Breast cancer | Polar M400 | Health Education | Any Internet-connected device to access Facebook | Daily physical activity tracking, physical activity tips |
| Timurtas et al [36] | Type 2 Diabetes | Ticwatch E | Improvement of glycaemic control | Smartphone | Exercise program at home, notifications to push exercise reminders |
| Trinquart et al [37] | Cardiovascular diseases | Apple Watch | Adherence to vital sign measurements | Smartphone | Personalization of notifications, messaging on different days and times |
| Wallace et al [38] | Mild traumatic brain injury and posttraumatic stress disorder | LG Urbane Android Wear | Management of stress and anxiety | Smartphone | Instructions and reminders for deep breathing |

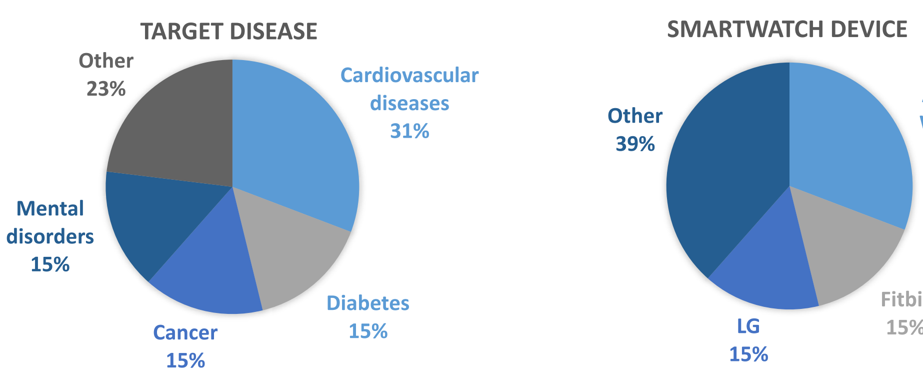


**Fig. 2.** Target disease and smartwatch devices of included studies.

monitoring of physical activity [27–30,32,33,35,36], delivery of educational content [27,33,35], and symptom tracking [31,32].

### 3.5. Participants and follow-up duration

The majority of the studies, i.e. 8 studies (61 %), were conducted in the US, whereas other studies were conducted in the UK, Netherlands, China, Republic of Korea, and Turkey. The average number of participants in the included studies was 32,465 (range 23—419297) (Table 3). The largest study in terms of sample size was the one by Perez et al [34], which employed 419,297 participants to examine the detection of atrial fibrillation through the Apple Watch. However, there were 7 studies that were small in size and included less than 100 participants [26,30–32,35,36,38]. The studies were conducted with people of middle and older age. The age of participants ranged between 30 and 78 years. There were 5 studies [26,28–30,33] with a mean age of participants over 60 years. The follow-up duration of the studies was on average 4.9 months with a range between 4 weeks and 18 months. The largest study in terms of follow-up (18 months), was the study by Abbott et al [26] for the prevention of diabetic foot ulcer recurrence. Most of the studies had a duration of 3 months or less [29–33,35,36,38].

### 3.6. Participant dropout

Participant dropout from research studies involving digital health interventions is a fundamental methodological challenge [39]. In the included studies, the dropout rate in the smartwatch intervention group ranged from 5 % [31] to 65 % [26], and it was 27 % on average.

**Table 3**
Properties and outcomes of included studies.

| Study | Study Design | Number of Participants | Age | Follow-up Duration | Outcome Measures | Statistically Significant Outcomes |
|---|---|---|---|---|---|---|
| Abbott et al [26] | Randomized controlled trial | 58 | Mean 67.1 (SD 9.6) years for control group, mean 59.1 (SD 8.5) years for intervention group | 18 months | Foot ulcer recurrence | Yes |
| Aguilar-Latorre et al [27] | Pragmatic randomized clinical trial | 188 | Mean 53.32 (SD 13.07) years | 6 months | Severity of depressive symptoms | Yes |
| Alexander et al [28] | Randomized controlled trial | 401 | Mean 64 years for the control group, mean 63 years for the intervention group | 1 year | Knee injury, osteoarthritis outcome score for joint replacement, quality of life, utilization of healthcare resources | Yes for the utilization of healthcare resources |
| Broers et al [29] | Randomized controlled trial | 150 | Mean 61.97 (SD 11.61) years | 3 months | Lifestyle change | Yes |
| Chae et al [30] | Controlled clinical trial | 23 | Mean 64.5 (SD 9.6) years for control group, mean 58.3 (SD 9.3) years for intervention group | 18 weeks | Functional assessment test, depression symptoms, shoulder range of motion | Yes for functional assessment and shoulder range of motion |
| Li et al [31] | Randomized controlled trial | 55 | Mean 41 years | 1 month | Adherence rate for oral antihistamines, total rhinoconjunctivitis symptom score | Yes |
| Low et al [32] | Randomized controlled trial | 26 | Mean 56.2 (SD 10.5) years | 57.2 days on average | Fitbit-measured sedentary behavior bouts and steps, quality of life and symptoms, 30-day readmissions, adherence | No |
| Marvel et al [33] | Nonrandomized control trial | 1064 | Mean 64.3 (SD 13.9) years | 1 month post-discharge | Unplanned all-cause readmissions | Yes |
| Perez et al [34] | Prospective, single-group, pragmatic study | 419,297 | Mean 41 (SD 13) years | 117 days (median monitoring time) | Atrial fibrillation | 84 % of notifications were concordant with atrial fibrillation |
| Pope et al [35] | Randomized controlled trial | 30 | Mean 52.6 (SD 9.3) years | 10 weeks | Physical activity, physiological, and psychosocial, variables, quality of life | No |
| Timurtas et al [36] | Randomized controlled trial | 75 | Mean 51.6 years | 12 weeks | HbA1c, six minute walk test, exercise behavior, muscle function, physical capacity | No |
| Trinquart et al [37] | Factorial blinded randomized trial | 655 | Mean 53 (SD 9) years | 6 months | Adherence to blood pressure and heart rate transmission | Yes, personalized notifications were associated with increased adherence |
| Wallace et al [38] | Pragmatic randomized clinical trial | 30 | Mean 37.67 (SD 6.90) years | 4 weeks | Goal attainment scaling for emotion regulation | Yes |

Table 4 presents in detail the dropout rate in each study, along with the documented reasons for dropout when available (dropout reasons were not reported in 3 studies). The most common dropout reasons were: a) problems or uncomfortability in engaging with technology [26,28,30,33,35], b) poor health [26,30,32,34], and c) time commitment [27,28,36]. Problems with smartwatch usage were reported as one of the reasons for dropout in 2 studies (15 %) [26,35].

### 3.7. Outcomes

The majority of the studies, i.e., in 10 out of 13 interventions (76 %), reported statically significant or clinically meaningful outcomes in favor of the intervention group [26–31,33,34,37,38]. The positive outcomes concerned foot ulcer recurrence, severity of symptoms of depression, utilization of healthcare resources, lifestyle changes, functional assessment and shoulder range of motion, medication adherence, unplanned hospital readmissions, atrial fibrillation diagnosis, adherence to self-monitoring, and goal attainment for emotion regulation. The 2 studies [31,33] which were found to be of high methodological quality according to EPHPP criteria, reported significantly positive outcomes of the intervention. In 3 studies (23 %) [32,35,36], non-significant outcomes for the intervention group were clearly reported, concerning sedentary behavior, physical activity, and glycaemic control. Interestingly, 2 of the 3 studies with negative outcomes, targeted physical activity outcomes for patients with cancer [32,35]. All 3 studies with negative outcomes were small in sample size (less than 75 participants), and they had short duration (less than 3 months).

### 3.8. Challenges with using smartwatches

Several studies have reported challenges with the use of smartwatch interventions, which might have affected patient engagement and study outcomes. More specifically, Abbott et al [26] reported that charging the smartwatch every two days and connecting with the smartphone app could be potential barriers. Necessity for daily charging, availability of a WiFi connection, and privacy protection for personal data collected by the smartwatch (e.g., videos) were reported as problems in the study by Li et al [31]. Data quality was reported as an issue in creating a robust machine-learning model for the recognition of rehabilitation exercises in the study by Chae et al [30]. The necessity to use a smartphone in addition to the participant's already existing personal phone to ensure synchronization with the smartwatch was reported as a challenge for user engagement in the study by Low et al [32]. In the study by Perez et al [34], the authors raised the issue of using the Apple Watch as a diagnostic tool. More specifically, the authors highlighted that notifications based on an irregular pulse from the Apple Watch photoplethysmography signal should not be used for a definitive diagnosis of atrial fibrillation, and the absence of notification did not exclude

**Table 4**
Dropout rate and reasons for dropout in included studies.

| Study | Dropout Rate (Intervention Group) | Reasons for Dropout |
|---|---|---|
| Abbott et al [26] | 65 % (21/32) | Too many other hospital appointment commitments because of comorbidity, problems engaging with the smartwatch technology, shoes were not a good fit, reluctance to wear a specific type of shoes for 18 months |
| Aguilar-Latorre et al [27] | 32 % (20/62) | Time incompatibility or a lack of interest in answering the questionnaires during the follow-up. |
| Alexander et al [28] | 37 % (97/257) | Screen failure, uncomfortable with technology, time commitment, postponed surgery, no follow-up information available |
| Broers et al [29] | 12 % (9/76) | N/A |
| Chae et al [30] | 45 % (10/22) | Unfamiliar with technology and experiencing difficulties in its usage, less interest in the conventional home rehabilitation program in the control group, disease deterioration |
| Li et al [31] | 5 % (2/40) | Poor compliance and lack of outcome indexes recording |
| Low et al [32] | 15 % (2/13) | Poor health |
| Marvel et al [33] | 7 % (16/216) | Death, overwhelmed to participate in a study, not interested in carrying an additional smartphone, not familiar with smartphones |
| Perez et al [34] | 57 % (1232/2161) | Failure to initialize the first study visit, poor health |
| Pope et al [35] | 25 % (4/16) | Size of smartwatch, Facebook privacy concerns |
| Timurtas et al [36] | 20 % (6/30) | Holidays, family reasons |
| Trinquart et al [37] | 33 % (95/281) | N/A |
| Wallace et al [38] | 6 % (2/32) | N/A |

possible arrhythmias.

## 4. Discussion

### 4.1. Main findings

This systematic review found that smartwatch interventions employed in the everyday life of patients of middle and older age to support their health and well-being may bring positive health-related outcomes, in terms of reduction of adverse events, lifestyle change, and adherence to treatment. Considering the statistically significant positive outcomes reported in 10 out of 13 included studies, the moderate methodological quality of most studies, and the considerable heterogeneity between included studies, the evidence of the effectiveness of smartwatch interventions can be considered modest overall. Therefore clinicians may consider to leverage smartwatch interventions in various clinical applications, given also the growing trend in smartwatch use.

In contrast with a previous review of smartwatches in healthcare by Reeder et al [3], this review has illustrated the most recent application and outcomes of smartwatch interventions in research studies targeting specific diseases, and not studies in a laboratory setting conducted with healthy subjects. Furthermore, this review has identified that smartwatch interventions can be effective on health outcomes other than physical activity, e.g. in terms of reduction of adverse events or better medication adherence, a factor which was not sufficiently considered in previous reviews on wearable devices [21,40–43].

### 4.2. Clinical implications

The clinical implication of this review is that patients facing various diseases could be benefited from using smartwatches in several cases. In cardiovascular diseases, smartwatch notifications and reminders can be used for improving lifestyle, reducing adverse events, identifying arrhythmias (atrial fibrillation), and improving adherence to care plans. In mental disorders, patients could be benefited in terms of managing their stress and anxiety and modifying their lifestyle behaviors, through instructions and educational content. Furthermore, exercise-based rehabilitation by automatically collecting physical activity data through smartwatches for knee arthroplasty and chronic stroke, was found to be effective in the utilization of healthcare resources and functional recovery. The smartwatches could also be used to support the reduction of foot ulcer recurrence in diabetic patients and the improvement of medication adherence in allergic rhinitis. On the contrary, studies targeting physical activity outcomes in patients with cancer did not present any positive outcomes. Considering the small sample of the included studies, as well as their risk for bias, future research should verify those findings.

### 4.3. Weaknesses of included studies

Some of the studies presented methodological quality weaknesses, e.g., in terms of blinding and number of withdrawals or dropouts, while other studies employed a small sample size or had a short follow-up duration. Interestingly, all studies that presented negative outcomes for the smartwatch intervention were small in sample size and short in duration. In this respect, we urge the research community to further conduct rigorous and longer-term clinical trials in order to provide more robust evidence of the impact of smartwatch interventions on health-related outcomes. The use of smartwatches in future clinical studies with children or adolescents would also be needed to examine clinical outcomes and unmet needs in young age groups. Furthermore, the evaluation of the implementation strategy has not been the focus of the included smartwatch research studies. A deeper exploration of implementation aspects such as engagement with smartwatches, collection of reliable smartwatch data, barriers and facilitators in smartwatch daily usage, would improve our understanding of the practicality and usefulness of smartwatch interventions [44].

### 4.4. Technical and usability challenges

The Apple Watch was the most used smartwatch in the studies. The delivery of various kinds of notifications to the user, e.g., for health behavior change, medication adherence, or alerting upon detection of abnormal sensor readings (for example irregular pulse), was the most common feature of the smartwatch interventions. Furthermore, it was found that in the majority of the cases, a smartphone app was used as a companion for the smartwatch in order to facilitate patient monitoring and guidance. Technical issues such as synchronization with the app, frequent smartwatch charging, availability of the Internet, and the burden of using an additional smartphone device to a patient's personal phone, were reported as barriers to user engagement.

No synchronization with a mobile app has been reported in the literature as a concerning technical issue which usually comes as a consequence of smartwatch low battery or smartwatch operating system updates [45]. To solve this issue, the users are advised not to use the battery saving mode on their devices, and the research team to reconfigure data sharing permissions as soon as data synchronization problems are identified. The issue with frequent smartwatch charging [46], could potentially be addressed through the development of a battery management plan with the goal to keep the device operational for the desired monitoring period [47]. The plan for example could consider to minimize energy consumption through evaluation of the energy demanding operations of the device, local data storage using lightweight databases, data offloading when the device is charging, or the employment of a black user interface background [48]. Furthermore, Internet connectivity issues could be tackled through infrastructure changes especially in rural areas with poor quality of Internet connection [49]. Finally, the use of smartphones in conjunction with smartwatches should be carefully weighed [46], considering the benefits (e.g., larger screen), but also the potential drawbacks when including an additional device, in terms of usability, technical robustness, and cost of the complete digital intervention.

### *4.5. Limitations*

The results of this study should be understood in light of its constraints. Although we examined the literature using two reputable databases (Scopus and PubMed), we accept that some studies may have been missed because they didn't match our defined search word criteria, or because no additional databases (e.g., Web of Science) were used. Another limitation is that our search was not updated to include studies published after April 2023. Publication bias in this review is possible, mainly because studies that report positive or significant results are more likely to be published and outcomes that are statistically significant have higher odds of being fully reported [50]. This review focused on the examination of the effectiveness of smartwatches on health-related outcomes for patients; however, a more comprehensive overview of smartwatch research by including also other types of studies, e. g., with a focus on implementation, usability, feasibility, or technical aspects, would be necessary to explore in depth additional relevant contributions. Grey literature was not looked into, apart from exploring ongoing trials in clinicaltrials.gov. Furthermore, due to the heterogeneity in the designs and outcomes of the included studies, we were unable to conduct a *meta*-analysis. The final sample of research studies that met our established inclusion criteria was small (n = 13), which might lessen the likelihood that the review findings will be generalizable.

## 5. Conclusion

Smartwatches have become increasingly integrated into people's daily lives, but can they play a pivotal role in current healthcare delivery? Based on the analysis conducted in this review, which indicated a small but growing body of smartwatch research studies with a potential positive effect on health outcomes, the answer could be yes to this question. However, more methodologically stronger and longer-term studies in intervention settings must be carried out to further demonstrate the practicality and benefits of employing smartwatches in therapeutic contexts.

Summary Points.

- Automated collection of health-related data and triggering of notifications were the main reasons for using smartwatches in interventional studies
- Smartwatch interventions have shown positive health outcomes for patients in most studies
- Challenges include: Charging frequency, Internet connection, data quality
- The evaluation of the implementation strategy in smartwatch research studies is needed
- The methodological quality of smartwatch studies should be improved

**Authors' contributions**

Author AT was responsible for the study conduction; Authors AT, HK, DK, AK, SS, and AA reviewed the literature; AT synthesized the literature according to the described methodology; AT wrote a first draft of the manuscript and all other authors contributed to the final version. All authors have read and agreed to the paper being submitted as it is.

## CRediT authorship contribution statement

**Andreas Triantafyllidis:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization. **Haridimos Kondylakis:** Writing – review & editing, Writing – original draft, Methodology. **Dimitrios Katehakis:** Writing – review & editing. **Angelina Kouroubali:** Writing – review & editing, Writing – original draft, Methodology. **Anastasios Alexiadis:** Writing – review & editing, Writing – original draft, Methodology. **Sofia Segkouli:** Writing – review & editing, Writing – original draft, Methodology. **Konstantinos Votis:** Writing – review & editing. **Dimitrios Tzovaras:** Writing – review & editing.

## Declaration of competing interest

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

## Appendix A: Ongoing clinical trials

**Table A1**
Ongoing clinical trials using smartwatches as found in clinicaltrials.gov (June 2024).

| NCT Number | Study Title | Study Status | Primary Outcome Measures | Interventions | Conditions |
|---|---|---|---|---|---|
| NCT05573633 | Diagnosis of Postoperative Atrial Fibrillation by a Smartwatch | RECRUITING | Variation of postoperative atrial fibrillation | Scanwatch | Atrial Fibrillation\|Cardiac Surgery |
| NCT06075082 | The Effect of the LEFT Smartwatch App as Sleep Positional Therapy for Nocturnal Gastroesophageal Reflux Symptoms | RECRUITING | Nocturnal Gastroesophageal Reflux Disease Symptom Severity and Impact Questionnaire (N-GSSIQ) | Smartwatch app | Gastroesophageal Reflux\|Heartburn |
| NCT05565781 | Smartwatch and External Holter Monitoring to Detect Atrial Fibrillation in Patients With Cryptogenic Stroke | RECRUITING | Increased probability of detecting atrial fibrillation | ECG smartwatch\|Insertable Cardiac Monitor (ICM)\|External ECG Monitoring | Paroxysmal Atrial Fibrillation\|Cryptogenic Stroke |
| NCT05686330 | Detection and Quantification of Atrial Fibrillation in High-risk Patients Using a Smartwatch Wearable (Apple Watch) | ENROLLING_BY_INVITATION | Incidence of atrial fibrillation | Apple Watch | Atrial Fibrillation |

(*continued on next page*)

**Table A1** (*continued*)

| NCT Number | Study Title | Study Status | Primary Outcome Measures | Interventions | Conditions |
|---|---|---|---|---|---|
| NCT06005233 | Smartwatches for Detection of Atrial Fibrillation (AFib) in Secondary Prevention of Cryptogenic Stroke | NOT_YET_RECRUITING | Sensitivity and specificity of atrial fibrillation detection | Smartwatch | Ischemic Stroke, Cryptogenic\|Transient Ischemic Attack\|Atrial Fibrillation |
| NCT04359238 | activeDCM – Interventional Clinical Trial of Individualized Activity and Exercise Programs to Improve Outcome in Dilated Cardiomyopathy Guided by Longitudinal Biosensing With Apple Watch | RECRUITING | Maximum oxygen uptake (VO2max) | Individualized exercise | Cardiomyopathy, Dilated\|Heart Failure |
| NCT05370469 | Real-Time Monitoring of Symptoms in Lung Cancer Patients Receiving Oral Targeted Therapies | ACTIVE_NOT_RECRUITING | Change in systolic blood pressure | Sensus Smartwatch Application\|RX Cap\|Fitbit Sense\|Surveys | Lung Cancer |
| NCT05509907 | Development of The Pediatric Physical Activity Tracking Platform (Pedi@Ctivity) and Smartwatch-based Big Data Analysis | RECRUITING | Physical Activity | Pedi@ctivity Analysis and Tracking Mobile Applications and Web Platform | Physical Activity\|Adolescent\|Childhood Rheumatic Disease |

## References


[1] F.V. Lima, V. Kadiyala, A. Huang, K. Agusala, D. Cho, A.M. Freeman, R. Druz, At the Crossroads! Time to start taking smartwatches seriously, Am. J. Cardiol. 179 (2022) 96–101, https://doi.org/10.1016/j.amjcard.2022.06.020.

[2] S.M. Lee, D. Lee, Healthcare wearable devices: an analysis of key factors for continuous use intention, Serv. Bus. 14 (2020) 503–531, https://doi.org/10.1007/s11628-020-00428-3.

[3] B. Reeder, A. David, Health at hand: A systematic review of smart watch uses for health and wellness, J. Biomed. Inform. 63 (2016) 269–276, https://doi.org/10.1016/j.jbi.2016.09.001.

[4] C.E. King, M. Sarrafzadeh, A Survey of Smartwatches in Remote Health Monitoring, J. Healthc. Inform. Res. 2 (2018) 1–24, https://doi.org/10.1007/s41666-017-0012-7.

[5] K. Park, M. Jeong, K. Kim, Usability evaluation of menu interfaces for smartwatches, J. Comput. Inf. Syst. 60 (2020) 156–165, https://doi.org/10.1080/08874417.2018.1425644.

[6] R. Dai, C. Lu, L. Yun, E. Lenze, M. Avidan, T. Kannampallil, Comparing stress prediction models using smartwatch physiological signals and participant self-reports, Comput. Methods Programs Biomed. 208 (2021) 106207, https://doi.org/10.1016/j.cmpb.2021.106207.

[7] T. Boillat, J.N. Siebert, N. Alduaij, F. Ehrler, GOFlow: Smartwatch app to deliver laboratory results in emergency departments – A feasibility study, Int. J. Med. Inf. 134 (2020), https://doi.org/10.1016/j.ijmedinf.2019.104034.

[8] A. Henriksen, M.H. Mikalsen, A.Z. Woldaregay, M. Muzny, G. Hartvigsen, L. A. Hopstock, S. Grimsgaard, Using Fitness Trackers and Smartwatches to Measure Physical Activity in Research: Analysis of Consumer Wrist-Worn Wearables, J. Med. Internet Res. 20 (2018) e9157.

[9] J. Chung, H.R. Brakey, B. Reeder, O. Myers, G. Demiris, Community-dwelling older adults' acceptance of smartwatches for health and location tracking, Int. J. Older People Nurs. 18 (2023) e12490.

[10] J.M. Bumgarner, C.T. Lambert, A.A. Hussein, D.J. Cantillon, B. Baranowski, K. Wolski, B.D. Lindsay, O.M. Wazni, K.G. Tarakji, Smartwatch algorithm for automated detection of atrial fibrillation, J. Am. Coll. Cardiol. 71 (2018) 2381–2388, https://doi.org/10.1016/j.jacc.2018.03.003.

[11] V. Dutot, V. Bhatiasevi, N. Bellallahom, Applying the technology acceptance model in a three-countries study of smartwatch adoption, J. High Technol. Manag. Res. 30 (2019) 1–14, https://doi.org/10.1016/j.hitech.2019.02.001.

[12] H.-Y. Choi, M. Keil, A.M. Baird, Intention to use smartwatch health applications: A regulatory fit and locus of control perspective, Inf. Manage. 59 (2022), https://doi.org/10.1016/j.im.2022.103687.

[13] E.Y. Ding, M. CastañedaAvila, K.-V. Tran, J. Mehawej, A. Filippaios, T. Paul, E. M. Otabil, K. Noorishirazi, D. Han, J.S. Saczynski, B. Barton, K.M. Mazor, K. Chon, D.D. McManus, Usability of a smartwatch for atrial fibrillation detection in older adults after stroke, Cardiovasc. Digit. Health J. 3 (2022) 126–135, https://doi.org/10.1016/j.cvdhj.2022.03.003.

[14] N. Kamal Basha, E.-C.-X. Aw, S.-H.-W. Chuah, Are we so over smartwatches? Or can technology, fashion, and psychographic attributes sustain smartwatch usage? Technol. Soc. 69 (2022) 101952 https://doi.org/10.1016/j.techsoc.2022.101952.

[15] T.-C. Lu, C.-M. Fu, M.-H.-M. Ma, C.-C. Fang, A.M. Turner, Healthcare Applications of Smart Watches. A Systematic Review., Appl. Clin, Inform. 7 (2016) 850–869, https://doi.org/10.4338/ACI-2016-03-R-0042.

[16] A. Jo, B.D. Coronel, C.E. Coakes, A.G. Mainous, Is there a benefit to patients using wearable devices such as fitbit or health apps on mobiles? a systematic review, Am. J. Med. 132 (2019) 1394–1400.e1, https://doi.org/10.1016/j.amjmed.2019.06.018.

[17] D. Nahavandi, R. Alizadehsani, A. Khosravi, U.R. Acharya, Application of artificial intelligence in wearable devices: Opportunities and challenges, Comput. Methods Programs Biomed. 213 (2022) 106541, https://doi.org/10.1016/j.cmpb.2021.106541.

[18] K. Bayoumy, M. Gaber, A. Elshafeey, O. Mhaimeed, E.H. Dineen, F.A. Marvel, S. S. Martin, E.D. Muse, M.P. Turakhia, K.G. Tarakji, M.B. Elshazly, Smart wearable devices in cardiovascular care: where we are and how to move forward, Nat. Rev. Cardiol. 18 (2021) 581–599, https://doi.org/10.1038/s41569-021-00522-7.

[19] C. Rodriguez-León, C. Villalonga, M. Munoz-Torres, J.R. Ruiz, O. Banos, Mobile and wearable technology for the monitoring of diabetes-related parameters: systematic review, JMIR MHealth UHealth 9 (2021) e25138.

[20] L. Sequeira, S. Perrotta, J. LaGrassa, K. Merikangas, D. Kreindler, D. Kundur, D. Courtney, P. Szatmari, M. Battaglia, J. Strauss, Mobile and wearable technology for monitoring depressive symptoms in children and adolescents: A scoping review, J. Affect. Disord. 265 (2020) 314–324, https://doi.org/10.1016/j.jad.2019.11.156.

[21] K.-J. Brickwood, G. Watson, J. O'Brien, A.D. Williams, Consumer-based wearable activity trackers increase physical activity participation: systematic review and meta-analysis, JMIR MHealth UHealth 7 (2019) e11819.

[22] L. Laranjo, D. Ding, B. Heleno, B. Kocaballi, J.C. Quiroz, H.L. Tong, B. Chahwan, A. L. Neves, E. Gabarron, K.P. Dao, D. Rodrigues, G.C. Neves, M.L. Antunes, E. Coiera, D.W. Bates, Do smartphone applications and activity trackers increase physical activity in adults? Systematic review, meta-analysis and metaregression, Br. J. Sports Med. 55 (2021) 422–432, https://doi.org/10.1136/bjsports-2020-102892.

[23] E. Mohammadi, M. Thelwall, S. Haustein, V. Larivière, Who reads research articles? An altmetrics analysis of Mendeley user categories, J. Assoc. Inf. Sci. Technol. 66 (2015) 1832–1846, https://doi.org/10.1002/asi.23286.

[24] S. Armijo-Olivo, C.R. Stiles, N.A. Hagen, P.D. Biondo, G.G. Cummings, Assessment of study quality for systematic reviews: a comparison of the Cochrane Collaboration Risk of Bias Tool and the Effective Public Health Practice Project Quality Assessment Tool: methodological research, J. Eval. Clin. Pract. 18 (2012) 12–18, https://doi.org/10.1111/j.1365-2753.2010.01516.x.

[25] N. Panic, E. Leoncini, G. de Belvis, W. Ricciardi, S. Boccia, Evaluation of the Endorsement of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) Statement on the Quality of Published Systematic Review and Meta-Analyses, PLOS ONE 8 (2013) e83138.

[26] C.A. Abbott, K.E. Chatwin, P. Foden, A.N. Hasan, C. Sange, S.M. Rajbhandari, P. N. Reddy, L. Vileikyte, F.L. Bowling, A.J.M. Boulton, N.D. Reeves, Innovative intelligent insole system reduces diabetic foot ulcer recurrence at plantar sites: a prospective, randomised, proof-of-concept study, Lancet Digit Health 1 (2019) e308–e318, https://doi.org/10.1016/S2589-7500(19)30128-1.

[27] A. Aguilar-Latorre, G. Pérez Algorta, C. Navarro-Guzmán, M.J. Serrano-Ripoll, B. Oliván-Blázquez, Effectiveness of a lifestyle modification programme in the treatment of depression symptoms in primary care, Front. Med. 9 (2022) 954644, https://doi.org/10.3389/fmed.2022.954644.

[28] J.S. Alexander, R.E. Redfern, P.J. Duwelius, K.R. Berend, A.V.J. Lombardi, D. A. Crawford, Use of a Smartphone-Based Care Platform After Primary Partial and Total Knee Arthroplasty: 1-Year Follow-Up of a Prospective Randomized Controlled Trial, J. Arthroplasty (2023), https://doi.org/10.1016/j.arth.2023.02.082.

[29] E.R. Broers, J. Widdershoven, J. Denollet, P. Lodder, W.J. Kop, M. Wetzels, I. Ayoola, J. Piera-Jimenez, M. Habibović, Personalized eHealth Program for Life-style Change: Results from the "do Cardiac Health Advanced New Generated Ecosystem (Do CHANGE 2)" Randomized Controlled Trial, Psychosom. Med. 82 (2020) 409–419, https://doi.org/10.1097/PSY.0000000000000802.

[30] S.H. Chae, Y. Kim, K.-S. Lee, H.-S. Park, Development and clinical evaluation of a web-based upper limb home rehabilitation system using a smartwatch and machine learning model for chronic stroke survivors: Prospective comparative study, JMIR MHealth UHealth (2020), https://doi.org/10.2196/17216.

[31] L. Li, Z. Wang, L. Cui, Y. Xu, H. Lee, K. Guan, The efficacy of a novel smart watch on medicine adherence and symptom control of allergic rhinitis patients: Pilot

study, World Allergy Organ. J. 16 (2023), https://doi.org/10.1016/j.waojou.2022.100739.
[32] C.A. Low, M. Danko, K.C. Durica, A.R. Kunta, R. Mulukutla, Y. Ren, D.L. Bartlett, D.H. Bovbjerg, A.K. Dey, J.M. Jakicic, A Real-Time Mobile Intervention to Reduce Sedentary Behavior Before and After Cancer Surgery: Usability and Feasibility Study, JMIR Perioper. Med. 3 (2020) e17292.
[33] F.A. Marvel, E.M. Spaulding, M.A. Lee, W.E. Yang, R. Demo, J. Ding, J. Wang, H. Xun, L.M. Shah, D. Weng, J. Carter, M. Majmudar, E. Elgin, J. Sheidy, R. McLin, J. Flowers, V. Vilarino, D.N. Lumelsky, V. Bhardwaj, W.V. Padula, R. Shan, P. P. Huynh, S. Wongvibulsin, C. Leung, J.K. Allen, S.S. Martin, Digital Health Intervention in Acute Myocardial Infarction, Circ. Cardiovasc. Qual. Outcomes 14 (2021) e007741.
[34] M.V. Perez, K.W. Mahaffey, H. Hedlin, J.S. Rumsfeld, A. Garcia, T. Ferris, V. Balasubramanian, A.M. Russo, A. Rajmane, L. Cheung, G. Hung, J. Lee, P. Kowey, N. Talati, D. Nag, S.E. Gummidipundi, A. Beatty, M.T. Hills, S. Desai, C. B. Granger, M. Desai, M.P. Turakhia, Large-Scale Assessment of a Smartwatch to Identify Atrial Fibrillation, N. Engl. J. Med. 381 (2019) 1909–1917, https://doi.org/10.1056/NEJMoa1901183.
[35] Z.C. Pope, N. Zeng, R. Zhang, H.Y. Lee, Z. Gao, Effectiveness of Combined Smartwatch and Social Media Intervention on Breast Cancer Survivor Health Outcomes: A 10-Week Pilot Randomized Trial, J Clin. Med. 7 (2018), https://doi.org/10.3390/jcm7060140.
[36] E. Timurtas, M. Inceer, N. Mayo, N. Karabacak, Y. Sertbas, M.G. Polat, Technology-based and supervised exercise interventions for individuals with type 2 diabetes: Randomized controlled trial, Prim. Care Diabetes 16 (2022) 49–56, https://doi.org/10.1016/j.pcd.2021.12.005.
[37] L. Trinquart, C. Liu, D.D. McManus, C. Nowak, H. Lin, N.L. Spartano, B. Borrelli, E. J. Benjamin, J.M. Murabito, Increasing Engagement in the Electronic Framingham Heart Study: Factorial Randomized Controlled Trial, J. Med. Internet Res. 25 (2023) e40784.
[38] T. Wallace, J.T. Morris, R. Glickstein, R.K. Anderson, R.K. Gore, Implementation of a Mobile Technology-Supported Diaphragmatic Breathing Intervention in Military mTBI With PTSD, J. Head Trauma Rehabil. 37 (2022) 152–161, https://doi.org/10.1097/HTR.0000000000000774.
[39] G. Eysenbach, The Law of Attrition, J. Med. Internet Res. 7 (2005) e402.
[40] T. Ferguson, T. Olds, R. Curtis, H. Blake, A.J. Crozier, K. Dankiw, D. Dumuid, D. Kasai, E. O'Connor, R. Virgara, C. Maher, Effectiveness of wearable activity trackers to increase physical activity and improve health: a systematic review of systematic reviews and meta-analyses, Lancet Digit, Health 4 (2022) e615–e626, https://doi.org/10.1016/S2589-7500(22)00111-X.
[41] A. Hodkinson, E. Kontopantelis, C. Adeniji, H. van Marwijk, B. McMillian, P. Bower, M. Panagioti, Interventions Using Wearable Physical Activity Trackers Among Adults With Cardiometabolic Conditions: A Systematic Review and Meta-analysis, JAMA Netw. Open 4 (2021) e2116382.
[42] A. Chan, D. Chan, H. Lee, C.C. Ng, A.H.L. Yeo, Reporting adherence, validity and physical activity measures of wearable activity trackers in medical research: A systematic review, Int. J. Med. Inf. 160 (2022) 104696, https://doi.org/10.1016/j.ijmedinf.2022.104696.
[43] T. Davergne, A. Pallot, A. Dechartres, B. Fautrel, L. Gossec, Use of Wearable Activity Trackers to Improve Physical Activity Behavior in Patients With Rheumatic and Musculoskeletal Diseases: A Systematic Review and Meta-Analysis, Arthritis Care Res. 71 (2019) 758–767, https://doi.org/10.1002/acr.23752.
[44] G.M. Curran, S.J. Landes, S.A. McBain, J.M. Pyne, J.D. Smith, M.E. Fernandez, D. A. Chambers, B.S. Mittman, Reflections on 10 years of effectiveness-implementation hybrid studies, accessed February 14, 2024, Front. Health Serv. 2 (2022), https://www.frontiersin.org/articles/10.3389/frhs.2022.1053496.
[45] K.J. Bin, L.R. De Pretto, F.B. Sanchez, L.R. Battistella, Digital Platform to Continuously Monitor Patients Using a Smartwatch: Preliminary Report, JMIR Form. Res. 6 (2022) e40468.
[46] R. Wu, M. Calligan, T. Son, H. Rakhra, E. de Lara, A. Mariakakis, A.S. Gershon, Impressions and Perceptions of a Smartphone and Smartwatch Self-Management Tool for Patients With COPD: A Qualitative Study, COPD J. Chronic Obstr. Pulm. Dis. 21 (2024) 2277158, https://doi.org/10.1080/15412555.2023.2277158.
[47] F. Di Rienzo, F. Righetti, M. Laurino, A. Greco, C. Marinai, I. Di Mambro, E. Melissa, N. Carbonaro, F. Bossi, G. Rho, L. Arcarisi, M. Zanoletti, P. Bufano, A. Tognetti, C. Vallati, Using Multiple Devices for Patient Monitoring in Clinical Studies: The TOLIFE Experience, in: 2024 IEEE Int. Conf. Pervasive Comput. Commun. Workshop Affil. Events PerCom Workshop, 2024: pp. 148–153. https://doi.org/10.1109/PerComWorkshops59983.2024.10502767.
[48] R. Ramezani, M. Cao, A. Earthperson, A. Naeim, Developing a smartwatch-based healthcare application: notes to consider, Sensors 23 (2023) 6652, https://doi.org/10.3390/s23156652.
[49] J.R. Sotzen, E.J. Stratman, Geographic variability in rural patient internet connectivity when accessing telehealth services from home: A retrospective analysis during the COVID-19 pandemic, J. Rural Health 39 (2023) 55–60, https://doi.org/10.1111/jrh.12695.
[50] K. Dwan, C. Gamble, P.R. Williamson, J.J. Kirkham, Systematic review of the empirical evidence of study publication bias and outcome reporting bias — an updated review, PLOS ONE 8 (2013) e66844.