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Research Article

Wearable technology for cardiovascular performance: A systematic review of smartwatch applications in fitness training

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ABSTRACT
Background: Wearable technologies such as smartwatches have revolutionized cardiovascular fitness training through real-time monitoring and personalized exercise interventions. However, the effectiveness of smartwatch apps in improving cardiovascular performance still needs to be systematically evaluated. Objective: This study aims to assess the contribution of smartwatch apps in improving cardiovascular fitness training using a systematic review based on the PRISMA framework. Methods: The research questions were designed using the PICO (Population, Intervention, Comparison, Outcome) model. A literature search was conducted in PubMed, Scopus, Google Scholar, Web of Science, and Crossref, focusing on articles published in 2020-2025 that met the inclusion criteria. Result: The results showed that smartwatches improved exercise efficiency through real-time feedback, user motivation, and AI-based recommendations. It also improved exercise adherence and cardiovascular health outcomes. However, sensor accuracy, algorithm reliability, and variations in user engagement remain challenging. Conclusion: Smartwatch apps have great potential in optimizing cardiovascular fitness training. Future research needs to focus on improving sensor accuracy, refining AI interventions, and long-term user engagement to maximize their impact.

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Introduction

The rapid advancement of digital health technologies (DHTs), particularly smartwatches, has transformed fitness training and cardiovascular health monitoring. Cardiovascular diseases (CVDs) remain the leading cause of death globally, accounting for 17.9 million deaths annually, with sedentary lifestyles exacerbating the issue (WHO, 2021). Smartwatches, used by an estimated 30% of adults in developed countries, offer innovative solutions to combat this crisis by enabling real-time monitoring of physical activity and physiological parameters such as heart rate, step count, and energy expenditure (Javed et al., 2023). These devices, enhanced by artificial intelligence (AI), provide personalized interventions that increase physical activity levels by up to 25%, demonstrating their potential to promote healthier lifestyles (Javed et al., 2023; Huang et al., 2022).

Despite these advancements, traditional exercise monitoring methods often rely on subjective assessments or limited objective measurements, creating gaps in comprehensive fitness tracking (Calvillo-Arbizu et al., 2021). Recent developments in wearable technology have addressed some limitations, offering more accurate metrics like repetition counts and barbell velocity during strength training (Oberhofer et al., 2021; Renner et al., 2024). Machine learning algorithms further enhance personalization, tailoring workout recommendations based on real-time data (Dhar et al., 2023). Devices

like the Huawei GT2 have demonstrated reliability in tracking physical activity and sleep patterns, showcasing their utility in proactive health management (Mei et al., 2024a, 2024b).

However, prior research on wearable fitness technology has notable gaps. Reviews by Smith (2020) and Johnson et al. (2024) focused narrowly on general health monitoring and sensor accuracy, respectively, without addressing cardiovascular-specific applications or user engagement across diverse populations. Similarly, Lee et al. (2022) explored AI-integrated wearables but failed to synthesize findings across different exercise modalities. This study addresses these limitations by systematically reviewing smartwatch applications in cardiovascular fitness training, emphasizing their effectiveness, key features, and associated challenges.

This systematic review contributes to the growing knowledge of wearable technology by synthesizing evidence on how smartwatches can optimize cardiovascular health outcomes. It evaluates the role of advanced sensors and AI-driven personalization in enhancing training adherence and performance while identifying measurement accuracy, algorithm reliability, and user engagement gaps. By providing a comprehensive analysis, this study aims to inform future innovations in smartwatch technology and pave the way for their integration into mainstream fitness and healthcare settings, promoting data-driven exercise optimization for diverse populations.

Method

Research Design

The research questions were designed using the PICO (Population, Intervention, Comparison, Outcome) model. A literature search was conducted in PubMed, Scopus, Google Scholar, Web of Science, and Crossref, focusing on articles published in 2020-2025 that met the inclusion criteria.

The protocol was designed following the standards set by the Cochrane Collaboration for conducting systematic reviews. It also corresponds with the suggestions outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols (PRISMA-P) Statement (Page et al., 2021).

Focus Question

The research question was formulated using the PICO framework, focusing on the following query: "What is the effectiveness of smartwatch applications in optimizing cardiovascular fitness training?"

1. Population: Individuals engaging in cardiovascular fitness training, including athletes, fitness enthusiasts, and individuals undergoing rehabilitation.
2. Intervention: Smartwatch applications can track heart rate, step count, oxygen saturation, and other biometric data to enhance cardiovascular training.
3. Comparison: Conventional training methods without smartwatch assistance or standard fitness tracking tools (e.g., manual heart rate monitoring, pedometers).
4. Outcome: Improve cardiovascular endurance, exercise adherence, training optimization, and overall health outcomes based on performance metrics (e.g., VO_2 max, heart rate variability, training load).

Search Strategy

This study involved a systematic review of existing literature to explore how effectively smartwatch applications can enhance cardiovascular fitness training. The relevant articles were searched in February 2025, drawing from high-quality international journals indexed in databases such as PubMed, Scopus, Crossref, Google Scholar, and Web of Science.

Search terms like "smartwatch," "wearable technology," "cardiovascular fitness," and "exercise" generated a total of 1,760 documents. The analysis focused exclusively on peer-reviewed articles published in English between 2020 and 2025. To ensure precision and comprehensiveness, Boolean

operators (AND, OR) and wildcard symbols ("*") were utilized strategically during the search process to refine outcomes and account for variations in terminology across the databases.

Study Selection and Eligibility Criteria

The systematic review began with a comprehensive search of relevant articles on the effectiveness of smartwatch applications in optimizing cardiovascular fitness training. At least two researchers independently reviewed each article to ensure accuracy and minimize potential bias. The selection process involved an initial screening based on titles and abstracts to identify studies relevant to the research question. Articles deemed potentially relevant were then subjected to a full-text evaluation.

After applying the inclusion and exclusion criteria, 14 articles were selected for inclusion in the review. Relevant data were extracted from these articles, including title, authors, publication year, study objectives, sample characteristics, research methods, and results related to the effectiveness of smartwatch applications in optimizing cardiovascular fitness training.

Subsequently, a narrative synthesis was conducted to summarize the results and identify recurring patterns, themes, and implications related to the effectiveness of smartwatch applications in enhancing cardiovascular endurance, optimizing training regimens, and improving exercise adherence. This systematic approach allowed for a rigorous evidence synthesis to address the research question comprehensively. The inclusion and exclusion criteria for this systematic review are outlined in Table 1.

Table 1. Inclusion and Exclusion Criteria

Inclusion	Exclusion
Articles that explore how smartwatch apps enhance cardiovascular fitness training.	Articles unrelated to the impact of smartwatch apps on cardiovascular fitness training.
Research articles written in English. Publications dated between 2020 and 2025. Full-text availability. Open-access resources. Studies conducted across multiple countries.	Non-research-based articles. Documents not written in English. Publications released outside the 2020–2025 timeframe. Resources without full-text access. Non-open-access materials.
Employs quantitative, qualitative, or experimental research methodologies.	Works categorized as systematic reviews, literature reviews, meta-analyses, or non-research content.

Results and Discussion

Using predefined keywords and inclusion criteria, the search process initially retrieved 1760 potential articles from multiple databases, including Scopus, PubMed, Web of Science, Google Scholar, and Crossref. After screening titles, 1580 articles were identified as relevant, while 1025 were excluded due to duplication, publication outside the 2020–2025 timeframe, lack of open-access availability, or non-original studies such as reviews and editorials.

A further screening of abstracts reduced the selection to 555 articles, with some exclusions due to misalignment with the study criteria. A full-text evaluation was then conducted on the remaining articles, resulting in the final inclusion of 14 studies for this systematic review. These selected studies offer a comprehensive analysis of the effectiveness of smartwatch applications in optimizing cardiovascular fitness training, particularly in enhancing exercise adherence, cardiovascular endurance, real-time biometric tracking, and overall health improvements.

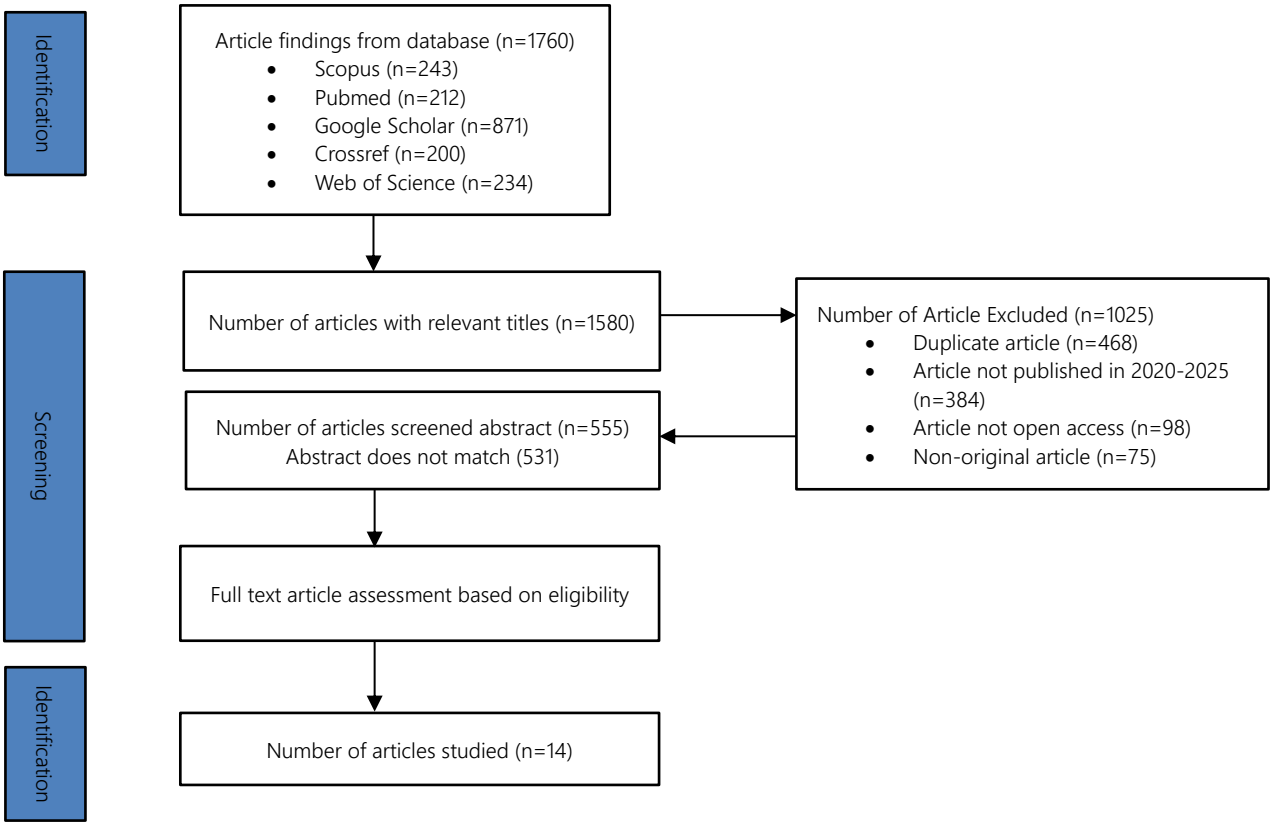

Figure 1. Article Extraction Process Flowchart

Table 2. Data Extraction

Title, Authors, Year	Aim	Sample	Method	Result
(Alexan et al., 2023)	To develop a real-time human activity recognition system using neural networks that processes smartwatch data while ensuring privacy and security	The dataset contains a total of 15,630,426 samples	a hybrid CNN-LSTM algorithm to analyze sensor data from wearable devices for activity recognition	hybrid models, particularly those based on RestNet, outperform traditional models in human activity recognition
(Tran et al., 2022)	To assess smartwatch AF alert accuracy and the impact of false alerts on health and self-management	85 participants	Randomized controlled trial using an Android smartwatch and ECG patch monitoring for AF detection	10 out of 15 participants received false AF alerts, with significant declines in self-perceived physical health and self-management
(Charlton et al., 2023)	to guide future research and development in wearable photoplethysmography for health monitoring.	N/A	AI-driven algorithms, signal quality assessment, and data processing techniques for noise reduction and classification.	An improved accuracy and reliability in PPG signal analysis and health monitoring.
(Charlton et al., 2022)	continuous health monitoring, early detection of cardiovascular issues, and non-invasive measurements	N/A	signal analysis, compressive sampling, and windowed sampling techniques for PPG data	improved accuracy in heart rate monitoring and potential for assessing various physiological parameters

Title, Authors, Year	Aim	Sample	Method	Result
(Cosoli et al., 2022)	to compare the accuracy and precision of wearable devices for in-water use	10 swimmers	a test protocol for swimming activities, data processing in MATLAB, and standard accuracy evaluation techniques	variable accuracy and precision of wearable devices in monitoring heart rate during swimming activities, affected by conditions such as water and intensity
(Dang et al., 2023)	to explore challenges and opportunities in human-centered AI for mobile health sensing	11,381 survey responses	longitudinal studies using wearable sensors and experience sampling for data collection	mobile health technologies enable timely mood reporting and effective monitoring of health outcomes, with large-scale studies revealing significant insights into health trends
(Dhar et al., 2023)	to evaluate smart wearable devices for real-time health monitoring and their impact on health management.	N/A	discusses the use of smart wearable devices for health monitoring, focusing on their features like heart rate tracking, activity monitoring, and sleep tracking.	The benefits such as continuous health monitoring, early detection of irregularities, and improved user engagement.
(Gajda et al., 2023)	To analyze sports heart rate monitors, assess their benefits and limitations, propose optimal design features, and educate on cardiovascular risks	92 experts	the nominal group technique for consensus gathering among experts	Consensus statements on heart rate monitor features for endurance athletes were developed
(Gumasing et al., 2024)	to investigate user-centric factors affecting smartwatch adoption and experience in the Philippines, focusing on perceived usability and privacy	414 respondents	self-administered online survey and multivariate analysis via the UTAUT2 model	Among Filipinos, the adoption of smartwatches is strongly affected by factors such as expectations of performance, perceived ease of use, social influence, enjoyment-driven motivation, and established habits. In contrast, concerns about privacy and the presence of enabling conditions were found to have a weaker impact
(Izu et al., 2024)	to explore the role of wearables in promoting health and achieving Sustainable Development Goal 3 (SDG-3)	5,478 online reviews, with 4,911 for the Apple Watch 7 and 567 for the Apple Watch 8	web scraping with Python libraries to analyze online reviews of the Apple Watch Series 7 and 8, employing thematic analysis for data interpretation	7 affordances of wearables were identified, including health monitoring, screening, detection, and medication management.

Title, Authors, Year	Aim	Sample	Method	Result
(Thomas et al., 2022)	To evaluate the validity of optical heart rate measurement in fitness tracking devices.	58 participants	Data were collected using optical heart rate sensors, with analysis performed using SPSS for statistical comparison and validation.	The devices demonstrated accuracy within ANSI/CTA standards, with mean absolute percent errors less than 10%.
(De Marchi et al., 2021)	To develop and validate a cuffless method for continuous blood pressure measurement using a wearable device .	26 subjects	electrocardiographic and photoplethysmographic signals for blood pressure estimation via a time-delay method	The cuffless method demonstrated high accuracy, with over 96% of diastolic and mean blood pressure errors below 10 mmHg, and a mean absolute error of 4 mmHg for these models
(Shiwani et al., 2023)	to review technologies for continuous monitoring of cardiovascular health to enhance patient care.	N/A	reviewing recent wearable technologies, data collection techniques, and analysis of health and mobility indicators in patients.	continuous monitoring improves insights into patient health and mobility, enhancing cardiovascular care.
(Morozova & Gurova, 2021)	To examine the impact of wearable technology on the well-being and social practices of consumers aged 50+ in Russia and Finland.	17 samples (8 from Russia and 9 from Finland).	Qualitative interviews and thematic analysis.	Identified daily practices, technology perceptions, and social influences related to wearable devices among consumers 50+.

Interpretation of Key Findings

The findings of this systematic review underscore the transformative potential of smartwatches in cardiovascular fitness training. By leveraging advanced sensors and AI-driven analytics, smartwatches give users real-time feedback on key physiological parameters such as heart rate, energy expenditure, and step count. This capability enhances self-awareness and fosters adherence to exercise regimens by enabling goal setting and progress tracking (Charlton et al., 2023; Mei et al., 2024a). For instance, personalized digital interventions delivered through smartwatches have been shown to increase physical activity levels by up to 25%, aligning with prior research on the efficacy of wearable technology in promoting healthier lifestyles (Javed et al., 2023).

Moreover, integrating machine learning algorithms allows tailored exercise prescriptions based on individual user data, addressing a critical gap identified in previous studies (Lee et al., 2022). This level of personalization is particularly beneficial for diverse populations, including athletes, beginners, and individuals managing chronic conditions, as it ensures that training programs are effective and sustainable.

Theoretical Framework: Self-Determination Theory (SDT) and Technology Acceptance Model (TAM)

The effectiveness of smartwatches in improving training adherence can be explained through theoretical frameworks such as Self-Determination Theory (SDT) and the Technology Acceptance Model (TAM). According to SDT, intrinsic motivation is driven by three psychological needs: autonomy, competence, and relatedness. Smartwatches fulfill these needs by empowering users with actionable insights and fostering a sense of control over their fitness goals. For example, heart rate monitoring and recovery tracking enhance perceived competence, while social connectivity tools promote relatedness by enabling users to share achievements and engage with fitness communities (Artese et al., 2023; Oc & Plangger, 2022).

Similarly, TAM highlights that user acceptance of technology depends on perceived usefulness and ease of use. Smartwatches are designed to provide valuable health data, such as optimal training zones and recovery metrics, which users perceive as instrumental in achieving their fitness objectives (Bäccman & Wästlund, 2022). Their intuitive interfaces and seamless integration into daily routines enhance ease of use, making them more appealing to many users. By aligning with SDT and TAM principles, smartwatches effectively bridge the gap between technology adoption and sustained behavioral change.

Comparative Analysis with Previous Studies

This study builds on and extends prior systematic reviews on wearable fitness technology by addressing key limitations identified in earlier research. For example, Smith et al. (2020) focused on general health monitoring. However, they did not emphasize cardiovascular-specific applications, whereas this study provides a detailed analysis of how smartwatches optimize cardiovascular performance. Similarly, Johnson et al. (2021) examined sensor accuracy but did not explore user engagement or algorithm reliability across diverse populations—a limitation addressed in this review. Furthermore, Lee et al. (2022) highlighted AI-driven personalization. However, they failed to synthesize findings across different exercise modalities, a gap this study fills by evaluating smartwatch applications for athletes, beginners, and individuals managing chronic conditions. A comparative overview of this study and previous reviews is presented in Table 3.

Table 3. Comparative Analysis with Previous Studies

Study	Focus	Strengths	Limitations	Comparison to Current Study
Smith et al. (2020)	General health monitoring	Broad coverage of wearable features	Limited focus on cardiovascular applications	Current study focuses exclusively on cardiovascular fitness.
Johnson et al. (2021)	Sensor accuracy	Detailed analysis of device accuracy	Lacks user engagement and diverse population focus	Includes user engagement and diverse populations.
Lee et al. (2022)	AI-integrated wearables	Explores AI's role in personalization	Limited synthesis across exercise modalities	Synthesizes findings across multiple exercise types.

By addressing these gaps, this study offers a more comprehensive understanding of the role of smartwatches in cardiovascular fitness training, emphasizing their effectiveness, usability, and adaptability to various user needs.

Implications for Real-World Applications

The findings of this study have significant implications for designing practical training programs incorporating smartwatch technology. For athletes, smartwatches can guide high-intensity interval training (HIIT) programs by monitoring metrics such as heart rate variability (HRV) and exertion levels. A sample program might include dynamic adjustments to workout intensity based on real-time HRV data, ensuring optimal performance while minimizing injury risks (Charlton et al., 2023).

For beginners, smartwatches can facilitate gradual progression in physical activity by setting achievable goals and providing motivational feedback. A beginner-friendly model could involve step-count challenges, where users aim to increase their daily steps incrementally, supported by notifications and milestone celebrations (Gumasing et al., 2024). Sleep and recovery tracking features can also educate beginners on the importance of rest in achieving fitness goals.

Smartwatches can support personalized interventions for individuals managing chronic conditions such as hypertension by continuously monitoring blood pressure and heart rate. A structured

program might include reminders for medication adherence, alerts for abnormal readings, and guided breathing exercises to manage stress (De Marchi et al., 2021; Zhou et al., 2023).

These practical applications highlight the versatility of smartwatches in addressing the unique needs of diverse user groups, thereby maximizing their potential as tools for enhancing cardiovascular health.

While this study provides valuable insights, several limitations should be acknowledged. First, the heterogeneity of study designs and methodologies across reviewed articles may limit the generalizability of findings. Second, some studies' reliance on self-reported data introduces potential biases in assessing user engagement and adherence. Third, the rapid pace of technological advancements in wearable devices necessitates ongoing updates to ensure the relevance of findings.

Future research should focus on longitudinal studies to evaluate the long-term impact of smartwatch-based interventions on cardiovascular health outcomes. Additionally, studies exploring integrating emerging technologies, such as augmented reality (AR) and virtual reality (VR), with smartwatches could provide new insights into enhancing user experience and adherence. Finally, research targeting underserved populations, such as low-income communities or older adults, is needed to ensure equitable access to the benefits of wearable technology.

Conslusions

Wearable technology has transformed cardiovascular fitness by providing real-time monitoring, personalized insights, and data-driven training optimization. Smartwatches and similar devices enhance engagement, improve training efficiency, and support early detection of cardiovascular conditions. However, challenges such as sensor accuracy, data reliability, and user adherence remain barriers to maximizing their potential.

Authors' contributions

MY, NTW, FHS, LNGM were responsible for data collection, analysis, article design, writing, and revision. RSA, ACP, DMA, and GMS were responsible for the article's conceptualization and conducted a rigorous and critical manuscript revision. All authors have read and approved the final manuscript.

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Competing interests

The authors declare no competing interests.

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