Wearable Devices for Training and Patient Monitoring:

A Comprehensive Review

Magdalena Kajzar, MD

Bonifraters Medical Center, St. Ks.Leopolda Markiefki 87, 40-211 Katowice, Poland

magdalena.kajzar12@gmail.com

https://orcid.org/0009-0005-4616-7636

Corresponding author: Magdalena Kajzar

magdalena.kajzar12@gmail.com

Abstract

Introduction:

Wearable technologies and remote patient monitoring (RPM) are transforming sports and healthcare by enabling continuous and real-time monitoring of various health parameters. These innovations hold significant potential for improving training outcomes in physical

rehabilitation and fitness programs, managing chronic diseases, and enhancing patient engagement.

Aim of the Study:

This review aims to summarize and highlight the most relevant findings on the current status, clinical applications, challenges, and prospects of wearable health-related sensing technologies in the context of training and chronic disease management.

Material and Methods:

A review of scientific publications from 2018 to 2024 was conducted using PubMed and Google Scholar databases. Keywords such as "wearable," "remote patient monitoring," "sensors," "training," and "chronic disease management" were used.

Conclusions:

Wearable devices are gaining popularity among the entire population, not only among individuals with chronic health conditions. The use of wearable technologies has shown promise in improving training and health outcomes by providing continuous monitoring, personalized care, and enhanced training programs. However, challenges such as data accuracy, privacy concerns, and integration with healthcare systems must be addressed and present opportunities for future advancements.

Keywords:

Wearable technologies, remote patient monitoring, chronic disease management, training, artificial intelligence.

Introduction

Wearable devices have seen a surge in popularity in recent years, driven by advancements in technology and increased affordability. These devices, initially popular among fitness enthusiasts, are now being designed and marketed to a broader audience, including individuals interested in health monitoring and chronic disease management. The widespread adoption of wearable technology is transforming both the sports and healthcare industries by enabling continuous and real-time monitoring of various health parameters [1, 2].

One of the key benefits of wearable devices is their ability to enhance training outcomes. By providing real-time data on metrics such as heart rate, movement patterns, and energy expenditure, these devices allow athletes and fitness enthusiasts to optimize their training regimens. This capability has been shown to significantly improve performance and reduce the risk of injuries by enabling precise monitoring and adjustments based on accurate, real-time feedback [3].

Wearable devices are also making significant strides in the management of chronic diseases. These technologies offer continuous monitoring of vital signs and other health metrics, providing valuable data that can help in the early detection and management of conditions such as diabetes, cardiovascular diseases, and respiratory illnesses. By facilitating remote patient monitoring, wearable devices empower patients to take an active role in their health management, leading to better health outcomes and enhanced patient engagement [4].

Moreover, the integration of artificial intelligence (AI) in wearable devices is opening new frontiers in personalized healthcare and fitness. AI algorithms can analyze the vast amounts of data generated by these devices, offering previously unattainable insights. From predicting potential health issues to suggesting personalized workout plans, AI-driven wearables are revolutionizing how we approach health and fitness [5]. The ability to provide intelligent feedback and predictive analytics makes AI-integrated wearable devices invaluable in preventive healthcare and performance enhancement. This review seeks to provide an overview of the key findings regarding the current state, clinical uses, challenges, and future potential of wearable health-related sensing technologies, particularly in the context of training and chronic disease management.

State of knowledge

Types of Wearable Devices

Wearable technology has made significant strides in sports performance enhancement and health monitoring. This chapter focuses on the features of wearable devices that have achieved notable commercial success and their applications in sports and health.

Sports Monitoring

Wearable devices designed for sports monitoring primarily include smartwatches and fitness trackers. These devices are equipped with various sensors such as accelerometers, gyroscopes, and Global Positioning System (GPS) modules to track and analyze athletic performance. The accelerometers and gyroscopes measure movement and orientation, providing detailed data on an athlete's speed, distance, and overall activity level. GPS modules add another layer by tracking the athlete's precise location, enabling the analysis of routes and distances covered during training sessions or competitions [6]. Additionally, heart rate monitors integrated into these wearables provide real-time data on cardiovascular performance, allowing athletes to adjust their intensity levels to optimize training and avoid overexertion. Advanced algorithms process this data to give insights into performance metrics such as pace, stride length, and recovery times, which are critical for tailoring training programs and improving athletic outcomes   [7].

Health Monitoring

Wearable devices play a crucial role in health monitoring and in managing and improving health outcomes. These devices, often worn as wristbands or patches, continuously measure vital signs such as heart rate, blood oxygen levels, and body temperature [7]. The data collected is crucial for monitoring chronic conditions like diabetes, cardiovascular diseases, and respiratory illnesses [8]. For instance, continuous glucose monitors (CGMs) track blood sugar levels in real time, providing diabetic patients with timely alerts and trends to manage their condition effectively [9]. Similarly, wearable ECG monitors can detect irregular heart rhythms, offering early warnings for potential cardiac events. Respiratory rate monitors help manage conditions such as chronic obstructive pulmonary disease (COPD) by providing data on breathing patterns and oxygen saturation levels. Wearable blood pressure monitors offer continuous monitoring, which is more convenient and less invasive than traditional cuff methods. These health wearables often sync with mobile apps and cloud services, enabling RPM by healthcare providers, who can access the data to make informed decisions about treatment plans and interventions [8, 9]

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Other Types of Wearable Devices

Beyond the widely popular smartwatches and fitness trackers, several other types of wearable devices are emerging with specialized applications. Smart clothing, such as shirts and socks embedded with sensors, offers an unobtrusive way to monitor physical activity and health metrics. These garments can measure heart rate, muscle activity, and body temperature, providing comprehensive data without the need for additional devices [7]. Augmented reality (AR) and virtual reality (VR) headsets are gaining traction in both sports training and rehabilitation, offering immersive environments for skill development and physical therapy [10]. Implantable wearables, though still in the early stages of development, promise to revolutionize health monitoring by providing continuous data from within the body, such as glucose levels or cardiac function. These innovative devices expand the possibilities of wearable technology, offering new ways to enhance sports performance and health management [11]   .

Applications of Wearable Devices in Sport

Wearable technology has revolutionized the sports industry by providing athletes and enthusiasts with real-time data and insights into their performance. These devices are equipped with various sensors that monitor key parameters, offering a detailed analysis of physical activity and enabling personalized training programs [2].

Key Parameters Monitored

Wearable devices in sports typically monitor a range of physiological and biomechanical parameters, including [5]:

1. **Heart Rate (HR)**: Monitors the intensity of the workout and cardiovascular health.
2. **GPS Tracking**: Measures distance, speed, and route, essential for outdoor activities like running and cycling.
3. **Accelerometers and Gyroscopes**: Track movement patterns, acceleration, and orientation to analyze biomechanics.
4. **Respiration Rate (RR)**: Provides insights into aerobic capacity and respiratory efficiency.
5. **Blood Oxygen Saturation (SpO2)**: Indicates the efficiency of oxygen delivery to muscles.

6. **Energy Expenditure**: Estimates calories burned during different activities.
7. **Stride Length and Frequency**: Important for runners to optimize their gait and reduce injury risk.

Accuracy and Reliability

The accuracy of wearable devices has improved significantly with advancements in sensor technology [12]. For instance, heart rate monitors in modern smartwatches and fitness trackers use photoplethysmography (PPG) to provide accurate readings comparable to chest strap monitors. GPS accuracy has also improved, offering precise tracking of routes and distances. However, some variability remains, particularly in challenging environments or with high-intensity movements.

Performance Improvement and Personalized Training

Wearable devices enhance athletic performance by providing personalized training programs based on real-time data. Athletes can track their progress, set goals, and receive instant feedback on their performance [13]. This continuous monitoring helps in identifying strengths and weaknesses, allowing for targeted improvements. For example, runners can adjust their pace and stride based on real-time data, while cyclists can optimize their cadence and power output.

Instant Feedback and Body Response

One of the key benefits of wearable devices is the ability to provide instant feedback during workouts. This feedback helps athletes understand how their bodies respond to different intensities and types of exercise. For instance, monitoring heart rate and respiration rate can indicate whether an athlete is working within their optimal training zones. Immediate adjustments can be made to avoid overtraining or undertraining, ensuring that each workout is effective and safe.

Wearable technology not only enhances performance but also contributes to injury prevention by monitoring biomechanical parameters and providing alerts on improper form or excessive load [13]. This proactive approach helps athletes maintain optimal health and achieve their fitness goals more efficiently.

In summary, wearable devices have become indispensable tools in the sports industry, offering accurate monitoring of key parameters, personalized training programs, and instant feedback. These advancements are driving significant improvements in athletic performance and overall fitness, making wearable technology a vital component of modern sports training.

Applications of Wearable Devices in Health Monitoring

Wearable devices have become crucial tools in the management of chronic diseases, offering continuous monitoring and providing valuable data that enhance patient care. This chapter focuses on how wearable devices improve the management of cardiovascular diseases, pulmonary diseases, diabetes, and hypertension, and their role in remote health monitoring and early disease detection.

Cardiovascular Diseases

Wearable devices play a significant role in managing cardiovascular diseases by continuously monitoring vital signs such as heart rate, heart rate variability, and electrocardiogram (ECG) readings [14]. These devices can detect arrhythmias, provide alerts for abnormal heart rhythms, and track recovery post-cardiac events [15]. Continuous monitoring allows for better management of conditions such as atrial fibrillation and heart failure.

- **Parameters Monitored**: Heart rate, ECG, heart rate variability, physical activity levels.
- **Applications**: Detecting arrhythmias, monitoring heart health post-surgery, managing heart failure.

Pulmonary Diseases

For pulmonary diseases such as COPD and asthma, wearable devices can monitor respiratory rate, oxygen saturation (SpO2), and peak expiratory flow [5, 15, 10]. These measurements help in assessing lung function and detecting exacerbations early, allowing for timely interventions. Continuous monitoring can reduce hospitalizations and improve the quality of life for patients with chronic respiratory conditions.

- **Parameters Monitored**: Respiratory rate, oxygen saturation, physical activity levels.
- **Applications**: Monitoring COPD, managing asthma, detecting early signs of respiratory distress.

Diabetes

Wearable devices for diabetes management, such as continuous glucose monitors, provide real-time data on blood glucose levels [1]. These devices help patients maintain optimal glucose control by providing alerts for hypo- and hyperglycemia and offering insights into how lifestyle factors like diet and exercise affect glucose levels [6]. Integrated insulin pumps can adjust insulin delivery based on CGM readings, further improving diabetes management.

- **Parameters Monitored**: Blood glucose levels.
- **Applications**: Real-time glucose monitoring, optimizing insulin delivery, preventing hypo- and hyperglycemia.

Hypertension

Wearable blood pressure monitors offer continuous and non-invasive blood pressure monitoring, providing valuable insights into a patient's cardiovascular health [16]. These devices help in managing hypertension by detecting trends and variations in blood pressure, enabling timely adjustments in medication and lifestyle changes [1].

- **Parameters Monitored**: Blood pressure, heart rate.
- **Applications**: Continuous blood pressure monitoring, managing hypertension, detecting white-coat and masked hypertension.

Remote Health Monitoring and Early Disease Detection

Wearable devices are integral to remote health monitoring, allowing healthcare providers to track patients' health metrics in real-time. This continuous flow of data facilitates proactive management of chronic diseases, reducing the need for frequent clinic visits and hospitalizations. RPM platforms integrate wearable device data, providing a comprehensive view of the patient's health status [17].

Moreover, the continuous monitoring capabilities of wearable devices support early disease detection [14]. By tracking health metrics over time, these devices can identify abnormal patterns and deviations from baseline values, prompting early diagnostic testing and intervention. This early detection can significantly improve outcomes, especially for conditions like atrial fibrillation, hypertension, and diabetes.

- **Applications**: Remote patient monitoring, early disease detection, proactive health management.
- **Integration with Health Services**: Wearable devices sync with health apps and cloud services, enabling healthcare providers to access real-time data and adjust treatment plans as needed.

Wearable technology thus plays a transformative role in chronic disease management, offering continuous monitoring, enhancing patient engagement, and supporting early disease detection. By integrating these devices into health services, healthcare providers can offer more personalized and proactive care, ultimately improving patient outcomes [18].

Continuous Monitoring, Patient Engagement, and Accuracy

Wearable devices have transformed healthcare by enabling continuous monitoring, enhancing patient engagement, and improving the accuracy of health data collection.

Continuous Monitoring

Continuous monitoring with wearable devices provides real-time data on vital signs and other health metrics, allowing for the timely detection of anomalies and immediate intervention. This capability is particularly beneficial for managing chronic conditions such as cardiovascular diseases, diabetes, and hypertension [1]. By continuously tracking parameters like heart rate, blood glucose levels, and blood pressure, these devices help maintain optimal health and prevent complications [19].

Patient Engagement

Wearable devices significantly enhance patient engagement by empowering individuals to take an active role in their health management [13]. Features such as real-time feedback, goal setting, and progress tracking motivate patients to adhere to their treatment plans and make healthier lifestyle choices. These devices also facilitate better communication between patients and healthcare providers, ensuring that patients are more informed and involved in their care [20].

Accuracy

The accuracy of wearable devices has improved with advancements in sensor technology. Modern devices use sophisticated algorithms and sensors to provide precise measurements of various health parameters. For example, photoplethysmography sensors offer accurate heart rate monitoring, while continuous glucose monitors provide reliable blood glucose readings. Accurate data from these devices is essential for effective health monitoring and management, allowing for better clinical decision-making and personalized care [1].

Wearable devices thus play a critical role in continuous health monitoring, enhancing patient engagement, and delivering accurate health data, all of which contribute to better health outcomes and more effective management of chronic diseases.

Future Trends in Wearable Devices

Wearable devices are poised to revolutionize healthcare and fitness further through advancements in data analytics, artificial intelligence, and emerging technologies [15]. These innovations promise to enhance the capabilities of wearables, making them more effective and integral to personal health management. Mobile devices are revolutionizing personalized care in areas like chronic disease management, cardiology, and mental health by providing real-time monitoring of conditions such as diabetes, heart disease, and anxiety. In respiratory care and rehabilitation, wearables track vital signs and physical progress, enabling tailored treatments and early intervention. Additionally, oncology is benefiting from personalized mobile tools that monitor patient recovery and treatment side effects, optimizing care based on individual health data.

Data Analytics and AI

The integration of data analytics and AI into wearable devices is transforming how health data is collected, analyzed, and utilized [6]. AI algorithms can process vast amounts of data generated by wearables to identify patterns, predict health issues, and provide personalized recommendations. Machine learning models improve the accuracy of health monitoring by continuously learning from new data, offering insights into a user's health that were previously unattainable [15].

Emerging Technologies

Emerging technologies such as flexible sensors, smart textiles, and implantable devices are expanding the horizons of wearable technology. Flexible sensors integrated into clothing can monitor a range of health metrics unobtrusively, providing continuous data without requiring the user to wear additional gadgets. Smart textiles embedded with sensors can track physiological parameters and even administer therapeutic interventions [14]. Implantable devices, though still in early development stages, offer the potential for continuous monitoring from within the body, providing highly accurate and reliable health data [7].

Potential Impact on Healthcare and Fitness

The potential impact of these advancements on healthcare and fitness is profound. In healthcare, wearables equipped with AI and advanced sensors can facilitate early diagnosis, personalized treatment plans, and improved patient outcomes. They enable proactive health management by alerting users and healthcare providers to potential health issues before they become critical [17]. In fitness, these technologies can provide detailed insights into workout effectiveness, help prevent injuries by analyzing movement patterns, and offer personalized training programs based on real-time data [3].

Wearable devices can also reduce healthcare costs by minimizing the need for frequent doctor visits and hospitalizations through continuous remote monitoring and early intervention [6]. The integration of wearables into telehealth services further enhances their utility, allowing for comprehensive patient care from a distance [10].

These future trends highlight the transformative potential of wearable devices, making them essential tools for enhancing health and fitness in the years to come.

Risks Associated with Wearable Devices

While wearable devices offer numerous benefits in health monitoring and sports performance, they also come with certain risks. One of the primary concerns is data privacy and security. Wearables collect and transmit sensitive health data, which could be vulnerable to cyberattacks or unauthorized access if not properly protected [17]. The use of cloud services and mobile apps to store and analyze data heightens this risk, as breaches in these systems

could lead to exposure to personal health information . Data accuracy is another challenge, as not all devices are reliable in different environments or for all users. Inaccurate readings could lead to incorrect health decisions or mismanagement of conditions, particularly in critical situations like diabetes or heart diseaseover-reliance on wearable technology may reduce personal health awareness, as users may depend on devices rather than developing a deep understanding of their body's signals and needs [16]. Finally, concerdevice wearability and long-term exposure to electromagnetic fields (EMF) generated by some devices have yet to be fully studied, raising potential health questions over prolonged use [2].

Conclusions

Wearable technology has rapidly advanced, significantly impacting sports performance and healthcare management. These devices have become integral for monitoring health parameters, enhancing training outcomes, and managing chronic diseases. The widespread use of smartwatches and fitness trackers highlights their utility in providing real-time data and personalized insights.

In sports, wearables offer detailed monitoring of activities, allowing athletes to optimize training and prevent injuries by tracking heart rate, GPS location, and movement patterns. This real-time feedback improves performance and ensures safety during workouts .

For chronic disease management, wearable devices continuously monitor vital signs, enabling early detection of health issues and timely interventions. Devices that measure heart rate, blood glucose, blood pressure, and respiratory rate are crucial for managing cardiovascular diseases, diabetes, hypertension, and pulmonary diseases. These wearables empower patients to control their health, enhance engagement, and improve outcomes .

The integration of data analytics and artificial intelligence enhances wearable capabilities. AI-driven insights and predictive analytics provide personalized recommendations and early warnings, transforming health monitoring and disease management. Emerging technologies, such as flexible sensors and smart textiles, promise to make wearables more unobtrusive and effective .

Despite significant advancements, challenges remain, particularly regarding data accuracy, privacy, and integration with healthcare systems. Addressing these issues is crucial for the continued growth and effectiveness of wearable technology .

Looking forward, wearable devices are poised to become even more essential in healthcare and fitness. Continuous innovation and AI integration will drive the development of more sophisticated and accurate wearables. These advancements will enhance real-time health monitoring, provide personalized care, and improve quality of life.

In conclusion, wearable technology represents a pivotal advancement in health and fitness. By offering continuous monitoring, enhancing patient engagement, and delivering accurate health data, wearable devices are set to play a transformative role in the future of healthcare and athletic performance.

Author's contribution

Conceptualization: Magdalena Kajzar

Methodology: Magdalena Kajzar

Software: Magdalena Kajzar

Check: Magdalena Kajzar

Formal Analysis: Magdalena Kajzar

Investigation: Magdalena Kajzar

Resources: Magdalena Kajzar

Data Curation: Magdalena Kajzar

Writing-Rough Preparation: Magdalena Kajzar

Writing-Review and Editing: Magdalena Kajzar

Visualization: Magdalena Kajzar

Supervision: Magdalena Kajzar

Project Administration: Magdalena Kajzar

The author has read and agreed with the published version of the manuscript.

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