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REVIEW ARTICLE

AI and machine learning applications in wearable health devices

Muhammad Nadir Shabbir[1,*], Duong Thuy Linh[2]

[1] *School of Economics, Renmin University of China, Beijing 100872, China*

[2] *Faculty of Management Sciences, National Economics University, Hanoi 100000, Vietnam*

*** Corresponding author:** Muhammad Nadir Shabbir, 20238018@ruc.edu.cn, muhammadnadir948@gmail.com

ABSTRACT

By enabling real-time monitoring, early diagnosis, and tailored therapies, wearable health technology combining artificial intelligence and machine learning has transformed healthcare. Wearables combine Internet of Things (IoT), cloud computing, and artificial intelligence (AI) using algorithms to monitor vital signs, including heart rate, blood glucose levels, and oxygen saturation. This enables predictive insights into health conditions, maximizes therapies, and supports remote healthcare options. Even if their potential use is rather high, data privacy, model generalization, regulatory validation, and accessibility remain issues. Generative artificial intelligence and federated learning both help privacy and performance. Predictive modeling, AR/VR, and blockchain technology will drive wearable health devices forward. Artificial intelligence-powered wearables impact world health since they provide competitively priced, scalable solutions for poor populations. By means of overcoming obstacles, multidisciplinary teamwork provides fair, safe, and changing healthcare service.

Keywords: wearable health devices; artificial intelligence; machine learning, health monitoring; technology

1. Introduction

Wearable health technology and artificial intelligence (AI) together represent a radical turn in modern healthcare. Originally used as fitness trackers, wearable devices driven by artificial intelligence have developed into indispensable tools for health monitoring, early diagnosis, and tailored therapy. Thanks to their rising power of artificial intelligence in processing and interpreting vast amounts of real-time data, these devices can already spot anomalies, forecast diseases, and support medical decision-making with hitherto unheard-of accuracy[1].

Wearable devices tracking significant health parameters, including heart rate variability, glucose levels, and blood oxygen saturation have inspired concepts in recent breakthroughs in sensor technology, data integration, and machine learning models[2]. Management of chronic diseases, mental health monitoring, and even early diagnosis of acute medical events including respiratory or cardiovascular problems are just a few of the more frequent applications for these technologies[3]. Furthermore, by means of remote monitoring and enhanced access to medical information, wearable artificial intelligence has enormous potential to reduce the load on healthcare institutions, especially in poor areas.

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Notwithstanding its promise, problems including data privacy, connectivity with present healthcare systems, and the need for robust validation studies still exist. If we are to ensure the public adoption and dependability of wearable health equipment driven by artificial intelligence, so reducing the gap between proactive and reactive healthcare solutions, these issues must be resolved as research develops. Although the developments in wearable technology and artificial intelligence provide great chances to enhance the delivery of healthcare, issues like data privacy and the necessity of consistent procedures remain important areas of future research and development importance. **Figure 1** elaborates on the summary of AI and ML applications in Wearable Health Technology.

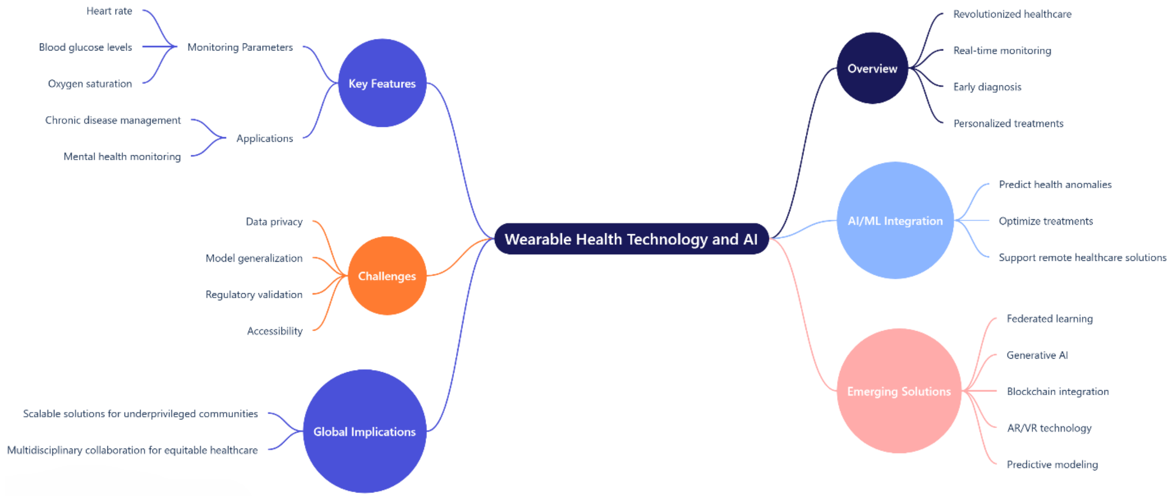

Figure 1. Chart of AI and machine learning applications in wearable health devices.

This research focuses on wearable health devices in chronic disease and mental health management due to their considerable potential to improve patient outcomes and solve critical healthcare concerns internationally. For example, chronic disorders like diabetes and hypertension require constant monitoring, which wearable gadgets easily deliver. Similarly, mental health management benefits from AI-powered wearables that give real-time stress and emotional state assessments, enabling early treatments. The real-world example includes the broad acceptance of products like the Fitbit Sense 2 and the Oura Ring in the U.S. and Europe. These technologies are crucial in chronic illness management and mental health tracking, displaying their real-world influence.

This review paper provides a theoretical overview of AI and machine learning in wearable health devices. This study discusses essential themes and insights from relevant and impactful field research, unlike systematic reviews, which follow a precise literature selection technique. The sources included were chosen for their relevance and contribution to understanding wearable technology's current state, difficulties, and future directions. The essay uses this method to detect and analyze important trends and theoretical frameworks without empirical evidence. This perspective allows a broad examination of the field while addressing its many challenges, including data quality, privacy, and model generalizability.

2. AI/ML technologies in wearable health devices

Wearable health devices (WHDs) have been turned by artificial intelligence and machine learning into powerful tools for real-time health monitoring, diagnosis, and individualized therapy. These technologies enable new approaches to the sense of wearables' massive data set management and interpretation.

2.1. Wearable health devices: AI/ML

The AI/ML fundamental ability of WHDs is their capacity to handle complex physiological data using learning algorithms. Regular approaches consist in supervised, unsupervised, and reinforcement learning[1].

- *Using input data, supervised learning teaches models using labeled datasets to classify or predict health issues. Using supervised learning techniques, arrhythmias or cardiac disease classification based on heart rate variability and rhythm patterns commonly uses electrocardiogram (ECG) data.*
- *Unsupervised learning finds latent patterns in data devoid of pre-labeled outcomes. K-means, also known as hierarchical clustering, detects trends in physical activity data including movement or behavior suggestive of a medical condition.*
- *Dynamic health systems use real-time sensor data to maximize treatment solutions for chronic diseases such as diabetes and hypertension by means of reinforcement learning*.

In more complicated scenarios, image recognition and time-series prediction are accomplished using deep learning—especially CNNs and RNNs. While RNNs may examine sequential data such as heart rate or activity to identify health threats such as cardiac events or seizures, CNNs can detect anomalies in skin temperature or oxygen levels from sensor data.

2.2. Information acquisition and processing

Wearable sensors log heart rate, blood pressure, ECG, respiration rate, skin temperature, and blood glucose levels. Raw data from these sensors, however, is sometimes corrupted by the surroundings or human motions or loud, incomplete. Signal filtering, normalizing, and feature extraction help artificial intelligence/machine learning systems provide accurate and reliable data input into models.

Wavelet transform and Fourier transform preprocessing techniques help to eliminate noise from ECG or heart rate data, therefore enhancing prediction models. When feature extraction techniques such as principal component analysis (PCA) reduce data dimensionality while preserving the most significant information, machine learning methods can better examine data.

2.3. Applied IoT with cloud computing using AI

Wearable devices, IoT, and cloud computing have dramatically expanded healthcare artificial intelligence/machine learning uses. Wearables provide real-time data for processing, storage, and analysis sent to cloud systems. More comprehensive health analytics and insights than the device alone are made possible by AI models housed in cloud platforms such as Google Cloud and Microsoft Azure that can manage massive volumes.

IoT in wearable health devices allows real-time monitoring and decision-making; edge computing preprocessing data on the device helps to lower latency and cloud reliance. IoT and artificial intelligence allow smart, customized health solutions. Using AI to foresee future occurrences and guide preventative actions, wearables tracking diabetes patients' blood glucose levels can warn consumers and clinicians when significant thresholds are exceeded.

2.4. Data management and model dependability problems

Varied health data makes implementing artificial intelligence/machine learning challenging for wearable health devices. Varied users, devices, and circumstances might produce quite varied data that influences model generalization[4]. This variability calls for transfer learning—that which adapts models from one dataset to another without retraining. Collecting various data without compromising sensitive data is made simpler with federated learning, in which models are trained across distributed devices under protection of user privacy and security.

3. Wearable medical device applications of AI/ML

Wearable health devices (WHDs) incorporating artificial intelligence and machine learning allow for constant, real-time monitoring of many health variables, therefore supporting customized healthcare[5]. Along with health information, these technologies offer personalized treatments, early disease identification, and improved chronic disease management. Below we address WHD AI/ML applications in real-time health monitoring, chronic illness management, fitness tracking, mental health monitoring, and remote patient care.

3.1. Real-time diagnosis and medical surveillance

Wearables track key health signs and provide real-time diagnosis by means of artificial intelligence and machine learning algorithms. Many wearables track heart rate, blood pressure, oxygen saturation, body temperature, ECG, which makes them great tools for ongoing medical evaluation[6].

Wearable ECG devices gather real-time ECG data that artificial intelligence systems examine to identify arrhythmias and other heart disorders. Machine learning algorithms taught on large ECG datasets can find minor anomalies suggestive of irregular heartbeats before clinical symptoms show. With an accuracy rate of 90%, Papalamprakopoulou et al.[7] demonstrated how precisely ML models might forecast atrial fibrillation (AF) in wrist-worn ECG sensors. KardiaMobile by AliveCor, a wearable ECG gadget, detects atrial fibrillation in real time. Studies reveal that its AI algorithms can detect abnormal cardiac rhythms before clinical signs with over 90% accuracy. The Apple Watch Series 8's ECG capability alerts users to suspected heart anomalies, enabling early medical treatments and better patient outcomes.

Wearable glucose monitoring gadgets driven by artificial intelligence can help diabetics regulate their blood sugar. By constantly reviewing sensor data, these devices can predict glucose fluctuations and provide users instantaneous feedback, therefore reducing the possibility of hypoglycemia or hyperglycemic episodes[8]. By anticipating patterns and warning of possible problems, Guan et al.[4] found that combining CGM with AI models can enhance diabetes treatment.

3.2. Managing chronic illnesses

Real-time, tailored treatment offered by artificial intelligence and machine learning is absolutely essential for the management of chronic diseases. AI-powered bracelets track blood pressure constantly for the treatment of hypertension. Artificial intelligence systems can forecast changes in blood pressure or crises of hypertension based on past trends and present measurements. Using ML models, Attivissimo et al. and Silva et al.[6,9] predicted high blood pressure episodes, therefore enabling quick lifestyle or medicine changes. As a case study, its real-time blood glucose monitoring and AI-driven insights enable patients to avoid hypoglycemic episodes by means of the Dexcom G7 Continuous Glucose Monitor.

Artificial intelligence-enabled wearables also enable the regulation of asthma and COPD. Wearable spirometers and smart inhalers log medicine use, air quality, and lung function. Artificial intelligence systems can use this information to forecast COPD flare-ups and asthma episodes, therefore notifying doctors and consumers before they worsen. Cuperus et al.[5] found via daily activity and respiratory data that AI-driven wearables could forecast COPD exacerbations with over 80% accuracy. Omron's wearable blood pressure monitor, HeartGuide, highlights how it may forecast hypertension crises depending on user patterns, therefore enhancing long-term health results.

3.3. Activity monitoring and fitness

Monitoring activities and tracking fitness are prevalent applications for wearable devices. Fitness trackers and smartwatches utilize AI/ML algorithms to analyze activity data and deliver personalized exercise insights, facilitating consumers in enhancing their training and mitigating injuries.

Personalized fitness recommendations are ideal for machine learning models as they may adapt workout regimens to align with an individual's activity habits, objectives, and health issues. A wearable device may monitor a user's step count, heart rate, and calorie expenditure to recommend workouts, depending on their fitness level. According to Khan et al.[10], Canali et al.[11], AI can determine the optimal exercise regimen for fat loss or cardiovascular wellness based on past performance, activity levels, and sleep patterns.

Artificial intelligence analyzes movement patterns to identify risks of injury or overtraining. Artificial intelligence-driven wearables can assess running gait or riding technique and offer suggestions for modifications to reduce repetitive strain injuries. Amendolara et al.[12]; Seçkin et al.[13] demonstrated that intelligent running shoes might utilize artificial intelligence to identify incorrect gait patterns, hence preventing shin splints and tendinitis.

The Fitbit Sense 2 and Garmin Forerunner 955 are popular fitness trackers that integrate AI for personalized health and fitness information. The Fitbit Sense 2 uses AI algorithms to reduce stress by monitoring HRV, skin temperature, and electrodermal activity. Its AI-driven stress detection technology suggests real-time relaxing practices to improve mental health. Instead, the Garmin Forerunner 955 measures VO2 max, training preparation, and sleep with AI to boost athletic performance. AI-powered adaptive training programs customize routines for fitness, activity, and recovery. Fitbit Sense 2 promotes wellness with a sleep quality score and stress detection. The Garmin Forerunner 955 gives fitness enthusiasts precise performance and recovery statistics. AI can optimize sports performance and monitor health, as shown in this comparison.

3.4. Mental health observation

Wearables and artificial intelligence are also helping with mental wellness. Wearables tracking sleep, stress, and emotion can highlight mental health issues. By means of HRV, skin temperature, and GSR data, AI algorithms can evaluate a person's mental state and identify early signs of stress, anxiety, and depression. Empatica's EmbracePlus wearable device monitors stress, anxiety, and emotions utilizing AI-driven HRV and EDA data. EmbracePlus predicts and manages anxiety sufferers' stress episodes. The Oura Ring also tracks sleep and provides mental health information. The device's individualized recommendations have improved stress management and sleep quality, according to research.

Feedback and customized advice from AI models help one to control mental wellness. AI-enabled wearables might suggest mindfulness or breathing exercises when tension is high. Abd-alrazaq et al.[14] demonstrated how wearables with HRV monitoring might forecast anxiety episodes, so enabling early intervention.

Wearables based on artificial intelligence are also increasingly used to monitor sleep patterns, therefore enabling diagnosis of restless leg syndrome, sleep apnea, and insomnia[15]. ML techniques find unusual sleep cycles, disruptions, and quality that can call for medical attention[16]. Wearables like the Oura Ring and WHOOP Strap track sleep using artificial intelligence and provide actionable data to raise mental well-being and sleep quality[17]. Moreover, **Figure 2** depicts the flowchart of AI treatment for mental health observation through personalized treatment plans and Virtual Therapists and chatbots.

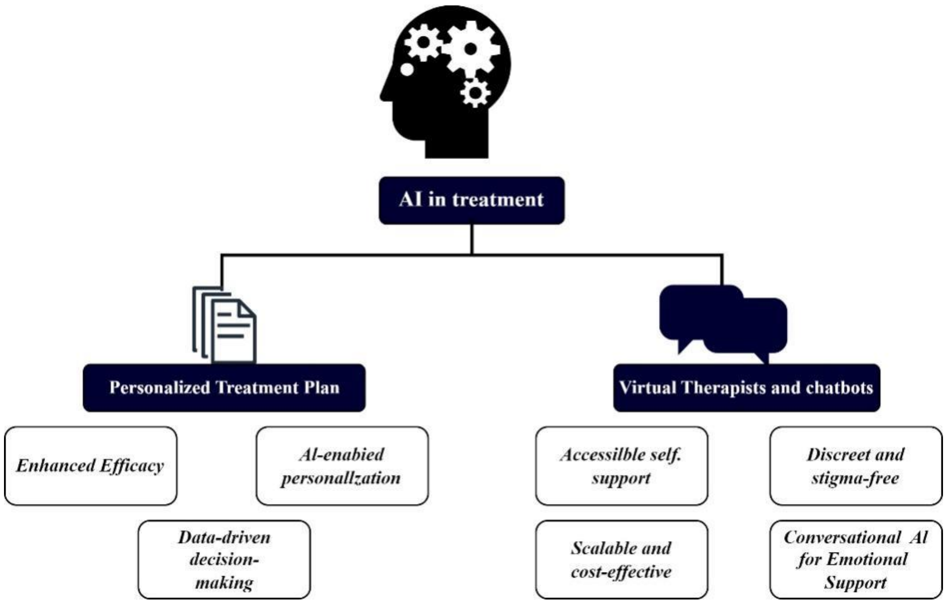

Figure 2. AI personalized and therapists chatbots treatment flowchart.

3.5. Remote surveillance and telemedicine

Remote patient monitoring and telemedicine demand wearables driven by artificial intelligence. In the age of telemedicine, wearables let doctors track patients in real time without in-person visits. Remote monitoring becomes more important during the COVID-19 epidemic since demand rises in this regard.

Wearables tracking heart rate, oxygen levels, and respiratory performance are needed by patients recovering from surgery or with chronic conditions. By analyzing this data, artificial intelligence (AI) can expose a patient's health pattern, enabling early reaction by healthcare providers. By means of timely interventions, Bhimaraj[18] discovered that wearables driven by artificial intelligence for remote heart failure monitoring enhanced patient outcomes.

By helping doctors understand large datasets, lowering human error, and supporting decision-making, telemedicine employing wearable gadgets and artificial intelligence can increase diagnosis accuracy. Particularly in underdeveloped places with few doctors, artificial intelligence, wearables, and telemedicine systems could revolutionize healthcare[19].

4. Wearable health device challenges and Limitations in AI/ML

Wearable health devices (WHDs) made by artificial intelligence and machine learning (ML) are valuable healthcare aids, but they must be generally adopted and clinically used by overcoming certain challenges.

4.1. Data quality and dependability

Reliability and data quality of wearable health devices are among their main problems. Wearables must measure heart rate, ECG, blood pressure, and glucose, hence, they depend on sensors. These sensors might generate false or insufficient data depending on noise, motion artifacts, skin contact, environmental conditions, and so on. Unreliable data can compromise artificial intelligence/machine learning algorithms, therefore lowering diagnosis and prediction accuracy[20].

Signal filtering and noise reduction are two advanced data preprocessing techniques that nevertheless find difficulty raising data quality. Motion artifacts in wearable ECG monitors have been found by Shajari et al.[3], Shumba et al.[21] to produce false positives or missed diagnosis, including atrial fibrillation. While maintaining the consistency and accuracy of wearables is challenging, AI model training calls for consistent, accurate data collection.

4.2. Issues involving security and privacy

Because of the sensitivity of health data, privacy and security become significant concerns in wearable health devices. Devices used in healthcare have to safely save and transmit information like activity data, glucose levels, and heart rate. Linking wearables to cloud servers runs them across hackers, data leakage, and illegal access[22].

Reducing these risks includes robust encryption, safe cloud platforms, and strict privacy rules. Gathering and distributing personal health information creates ethical questions regarding consent and data ownership even with these safeguards. Cilliers[22], Bouderhem[23] observed that emphasizing the requirement of openness and informed permission in wearable health technology development, consumers might not know how their data is used.

4.3. Difficulties with validation and control

Before being used in clinical practice, wearable health devices driven by artificial intelligence have to pass thorough regulatory examinations. Considered medical equipment in many places, medical wearables need rigorous regulatory clearance. US artificial intelligence-powered ECG monitors have to be FDA-approved for safety and effectiveness.

Slow, costly, and including significant clinical trials to verify AI algorithm correctness and efficacy, the regulatory approval process for AI-driven products is Standard regulatory approaches are too slow to keep up with AI progress, hence[24] advised new frameworks to oversee artificial intelligence in medical devices. AI models lacking regulatory supervision or validation could harm or misdiagnose patients. Manufacturers can address user concerns and boost WHD trust by adding comprehensive privacy safeguards with scalable validation frameworks. Encryption, federated learning, and blockchain technologies improve security and ensure that AI models in these devices are accurate, safe, and responsive to real-world settings. The widespread deployment of wearable health devices in healthcare systems requires this holistic approach.

4.4. Model generalizing and prejudice

Wearable health devices’ artificial intelligence/machine learning algorithms often fail in generalizing[8]. Usually, these models are trained on particular datasets that might not represent global variation. Physiological differences could influence health metrics, so a model developed on Caucasian data could not be as successful for other ethnicities.

Particularly in the healthcare industry, artificial intelligence bias can misjudge demographic groups. Researchers are producing more varied and representative datasets to help with this. Investigated to improve model generalization and lower bias by training models across devices and populations while preserving privacy are transfer learning and federated learning.

4.5. Accessibility and user acceptance

For wearable health devices, user acceptance and accessibility remain challenges even with technological developments. Technical trust issues or AI forecast accuracy concerns have many people skeptical about artificial intelligence-driven health monitoring. Some wearable devices could be difficult for elderly people or those without technological knowledge in particular[17].

Wearable health technologies are not easily available to low-income rural people. They might not have internet, cellphones, or the money to acquire modern wearables; hence, these technologies could not be within reach. Manufacturers have to design reasonably priced, user-friendly devices for general society to break free from these limitations.

5. Future directions and opportunities

Better personalizing, more applications, and worldwide health benefits will all be made possible by future artificial intelligence in wearable health devices (WHDs). As it develops, artificial intelligence will provide fresh approaches to healthcare delivery and worldwide results.

5.1. Artificial intelligence/wearable technology develops

Federated learning and generative artificial intelligence will help wearable health gadgets. Generative artificial intelligence systems can replicate and project intricate health events in WHDs. Generative models, for instance, may replicate the spread of disease to enable clinicians to modify their treatment plans or forecast negative results. These models might enable real-time, customized treatment for chronic diseases such as diabetes and cardiovascular disease.

A new machine learning technique called federated learning shields user privacy while letting several devices teach models on local data. This approach is feasible for wearables, as continuous model improvement without compromising sensitive health data is possible. Based on user health data, this might create privacy-protected artificial intelligence models. Such models can generate more accurate forecasts and recommendations since they adjust to changes in personal health.

5.2. Including emerging fields

Especially in rehabilitation and mental health, AR and VR will improve wearable health devices over time. AR/VR allows wearables to track brain activity or heart rate to generate immersive therapeutic experiences[5,21]. Wearable sensors and virtual reality could offer physical rehabilitation, cognitive treatment, and customized, real-time pain management[25]. Particularly in mental health treatment, applications could raise patient participation and clinical results.

Wearable health gadgets are also becoming absolutely essential for precision and predictive medicine. Wearables driven by artificial intelligence can provide tailored healthcare recommendations based on genetic data, lifestyle decisions, and real-time health measurements that improve medication accuracy. A case study presented AR-based physical therapy apps with wearable sensors for real-time stroke rehabilitation feedback. Advanced blockchain technology, including secure, decentralized ledgers for wearable health data storage, ensured privacy and interoperability[2,16]. Rehabilitation methods like NeuroRehab VR use AR/VR and wearable sensors for stroke healing. I use MedRec to discuss blockchain's usefulness in secure, decentralized data management. I also suggest novel blockchain-federated learning solutions for wearable health device privacy and scalability[23,26].

5.3. Scalability and global influence

Artificial intelligence-based wearables can be developed to assist underprivileged areas with better healthcare. In settings with limited resources and few healthcare personnel, wearables offer low-cost, non-invasive ways of health monitoring[27]. Early identification of health risks by these devices' artificial intelligence models—even in far-off areas—allows rapid responses and reduces the burden on the healthcare system.

Artificial intelligence-driven wearables could also significantly influence global health. These technologies provide cheaply priced, customized treatment capable of reducing health inequalities. Through tracking and forecasting of infectious diseases, chronic ailments, and mother health, AI-driven wearables could help to solve world health issues. Their involvement in global health initiatives could help people to take charge of their health, especially in low-income communities without traditional medical services.

6. Conclusion

Artificial intelligence and machine learning—along with real-time, tailored monitoring and prediction insights—have revolutionized wearable health devices (WHDs). Thanks to these technologies, WHDs have evolved from early medical diagnosis, mental health monitoring, and management of chronic diseases to encompass fitness tracking. Artificial intelligence and machine learning algorithms in WHDs can produce actionable insights generated by means of extensive sensor data evaluation that enhance patient outcomes, lower healthcare costs, and increase proactive health management.

Mental health assessments, early cardiovascular disease diagnosis, customized exercise recommendations, and continuous vital sign monitoring—e.g., heart rate, blood glucose, ECG)—are among the wearable artificial intelligence and machine learning applications. Among other artificial intelligence methods, deep learning and federated learning have improved the accuracy and flexibility of these devices, hence raising their personal relevance and value for users. Wearables can discover health irregularities before they start to cause problems thanks to artificial intelligence.

Still, some obstacles have to be overcome if we are to completely achieve WHDs driven by artificial intelligence. Among these are data quality, privacy, security, legal issues, and artificial intelligence model biases. To address these issues, researchers, doctors, legislators, and device companies have to cooperate. Wearable health device AI technologies must be secure, dependable, and easily available to all by means of multidisciplinary cooperation.

Wearable health technologies will be shaped ultimately by creativity, smart control, and health equity. By eliminating present constraints and increasing cross-sector collaboration, AI-powered WHDs will transform healthcare and enable individualized and predictive treatment worldwide.

The school environment is an ideal setting for promoting physical activity. Wearables have previously been implemented as intervention tools within the school environment[25]. Yet, the use of wearables as a teaching and support tool continues to pose challenges within P.E. lessons due to the unique nature of the class.

Author contributions

Author contributions: Conceptualization, MNS and DTL; methodology, DTL; software, MNS; validation, MNS and DTL; formal analysis, MNS; investigation, DTL; resources, MNS; data curation, MNS; writing—original draft preparation, MNS; writing—review and editing, DTL; visualization, MNS; supervision, DTL; project administration, MNS; funding acquisition, DTL. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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