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A review of wearable technology in healthcare: Monitoring patient health and enhancing outcomes

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Abstract

Wearable technology has emerged as a transformative force in the healthcare landscape, reshaping the way patient health is monitored and healthcare outcomes are enhanced. The paper delves into various types of wearables, including fitness trackers, smartwatches, and medical wearables, elucidating their functionalities and applications in the healthcare domain. The review emphasizes the profound influence of wearable technology on patient monitoring, encompassing continuous health tracking, remote patient monitoring, and chronic disease management. Through real-time data collection and analysis, wearables enable early detection of health abnormalities and empower healthcare providers to offer timely interventions, thereby reducing hospital readmissions. The role of wearables in chronic disease management is examined, showcasing their potential in tailoring personalized treatment plans and facilitating proactive health management. Furthermore, the paper explores the broader implications of wearable technology in enhancing healthcare outcomes. Wearables contribute to improved patient engagement by providing individuals with access to their health data, fostering a sense of empowerment and accountability. The review underscores the shift towards personalized healthcare, where wearables play a pivotal role in tailoring treatment plans based on individual health data and leveraging predictive analytics for disease prevention. Despite the promising advancements, challenges such as data security, privacy concerns, and integration with existing healthcare systems are discussed. Strategies to address these challenges and enhance user adoption and adherence to wearable technology are explored, recognizing the importance of a holistic approach in realizing the full potential of wearables in healthcare. This review serves as a comprehensive guide for researchers, healthcare providers, and policymakers, offering insights into the evolving landscape of wearable technology and its profound impact on monitoring patient health and improving healthcare outcomes.

Keywords: Wearable; Technology; Healthcare; Monitor; Patient; Health; Outcomes

1. Introduction

Wearable technology has undergone a remarkable evolution, transforming from mere gadgets into integral components of healthcare strategies (Gao et al., 2019; Dunn, 2018). The integration of wearables in the healthcare landscape has been spurred by advancements in sensor technology, data analytics, and a growing emphasis on patient-centered care (Steinhubl et al., 2015; Sharma & Conner, 2019). The inception of wearable technology can be traced back to basic fitness trackers, evolving into sophisticated devices capable of monitoring a myriad of health parameters (Gao et al., 2019). The journey from step counters to comprehensive health monitors has been marked by innovations in sensor miniaturization, battery life, and connectivity. Understanding this evolution sets the stage for comprehending the current landscape of wearables in healthcare (Dunn, 2018). The healthcare industry has increasingly embraced wearables as valuable tools for monitoring and managing patient health (Steinhubl et al., 2015). From consumer-grade devices to medical wearables prescribed by healthcare professionals, wearables have become instrumental in providing

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real-time health data. The integration of wearables into healthcare ecosystems has implications for preventive care, chronic disease management, and overall healthcare delivery (Sharma & Conner, 2019). This review aims to provide a comprehensive overview of the multifaceted role wearables play in healthcare (Patel et al., 2015). It explores the diverse categories of wearables, ranging from fitness trackers and smartwatches to specialized medical wearables, elucidating their functionalities and potential applications in healthcare settings. By examining the breadth of wearables, the review sets the stage for a nuanced understanding of their impact on patient health monitoring (Lukowicz et al., 2004). The primary focus of this review is on the pivotal role wearables play in monitoring and assessing patient health (Ding et al., 2016). From tracking vital signs to providing continuous health insights, wearables offer a dynamic and real-time approach to patient monitoring. This section underscores the significance of wearables in contributing valuable data for healthcare professionals to make informed decisions (Dolan et al., 2018). This paper contends that wearable technology has evolved beyond a consumer gadget to become an integral tool in healthcare (Swan, 2012). The thesis asserts that the integration of wearables, encompassing fitness trackers, smartwatches, and medical wearables, has revolutionized patient health monitoring. By leveraging advancements in technology, wearables contribute to enhanced outcomes, personalized healthcare, and a paradigm shift towards proactive health management (Wang et al., 2015).

1.1. Types of wearable technology in healthcare

Wearable technology in healthcare encompasses a diverse range of devices, each designed to monitor and enhance various aspects of patient health Fitness trackers represent the entry point of wearable technology into the healthcare arena (Chan et al., 2012). These devices go beyond simple step counting, incorporating advanced sensors to monitor various physical activities and exercise routines. They track metrics such as distance traveled, calories burned, and even specific exercise types, providing users with comprehensive insights into their fitness levels (Chen et al., 2018). Fitness trackers seamlessly integrate with health and wellness applications, fostering a holistic approach to individual well-being. By syncing with mobile apps, these wearables allow users to set fitness goals, track progress over time, and receive personalized recommendations. The synergy between fitness trackers and health apps encourages users to actively engage in their health management (Patel et al., 2015).

Smartwatches have evolved beyond being mere timekeeping devices to sophisticated health monitoring tools. Equipped with sensors such as heart rate monitors, accelerometers, and gyroscopes, smartwatches provide real-time data on vital signs. Users can effortlessly track their heart rate, detect irregularities, and gain insights into their overall cardiovascular health (Kroll, 2019). Beyond monitoring physiological parameters, smartwatches contribute to medication adherence and overall health management. Users receive timely notifications for medication schedules, hydration reminders, and other health-related tasks (Lee et al., 2023). The integration of such features enhances the proactive nature of smartwatches in promoting healthier lifestyles (Vegesna et al., 2019). Medical wearables represent a specialized category designed for continuous monitoring of vital signs. These devices, often prescribed by healthcare professionals, track parameters such as heart rate, blood pressure, and oxygen saturation. The continuous stream of real-time data facilitates early detection of anomalies and supports timely medical interventions (Bonato, 2019). Medical wearables play a crucial role in enhancing the connectivity between patients and healthcare providers. By integrating with medical databases, these wearables ensure that real-time patient data is accessible to medical professionals, enabling informed decision-making and personalized healthcare delivery (Rumschlag et al., 2018).

1.2. Impact on patient monitoring

Wearable technology has revolutionized the landscape of patient monitoring, offering a dynamic and real-time approach to healthcare. Wearables enable real-time monitoring of vital signs, providing a continuous stream of data on parameters such as heart rate, blood pressure, and respiratory rate (Dias et al., 2018). This real-time feedback allows individuals and healthcare professionals to promptly detect deviations from baseline values, facilitating early intervention in case of anomalies (Wang et al., 2016). The continuous nature of wearable monitoring offers the potential for early detection of health abnormalities. Patterns and trends in vital sign data can be analyzed over time, allowing for the identification of subtle changes that may precede the onset of a medical condition (Rothmanet et al., 2013). This proactive approach enhances the likelihood of timely medical intervention (Inan et al., 2017). Wearables facilitate remote patient monitoring, allowing healthcare providers to access real-time health data without the need for physical presence. This capability is particularly valuable for individuals with chronic conditions, post-surgery recovery, or those requiring ongoing medical attention. Remote monitoring enhances accessibility to healthcare services, contributing to improved patient outcomes (Elsden et al., 2020). Wearable devices play a pivotal role in reducing hospital readmissions by providing a seamless means of continuous monitoring post-discharge. Patients equipped with wearables can be remotely monitored for signs of deterioration or complications, enabling timely interventions and preventing unnecessary hospital visits (Rumschlag et al., 2018). Wearables have emerged as valuable tools in the management of chronic diseases such as diabetes, hypertension, and respiratory conditions. These devices continuously monitor relevant health metrics, empowering individuals and healthcare providers with actionable insights for better disease management and lifestyle adjustments (Cho et al., 2018). The continuous data generated by wearables contribute to the personalization of treatment plans. Healthcare providers can tailor interventions based on real-time health insights, optimizing medication regimens, and recommending lifestyle modifications specific to individual patient needs. This personalized approach enhances the efficacy of chronic disease management (Dorfman et al., 2013).

1.3. Enhancing healthcare outcomes

Wearable technology goes beyond mere data collection; it has a profound impact on healthcare outcomes by influencing patient engagement, enabling personalized healthcare, and contributing to positive shifts in preventive care approaches (Bhatt and Chakraborty, 2023). Wearables empower individuals by providing direct access to their health data. Through user-friendly interfaces and mobile applications, patients can easily monitor their vital signs, track progress, and gain insights into their health status (Baig et al., 2015). This increased transparency fosters a sense of ownership and responsibility for one's health (Patel et al., 2015). Wearables encourage proactive health management by providing real-time alerts and actionable insights. Individuals can set health goals, receive reminders for physical activity or medication adherence, and actively participate in monitoring and improving their well-being. This shift towards proactive engagement aligns with preventive healthcare strategies (Vegesna et al., 2019). Wearables contribute to personalized healthcare by continuously collecting individual health data (Vijayan et al., 2021). Healthcare providers can utilize this real-time information to tailor treatment plans according to the unique needs and responses of each patient. This personalized approach enhances the effectiveness of interventions and improves overall patient outcomes (Cho et al., 2018). Wearables, coupled with advanced analytics, enable predictive insights into health conditions. Machine learning algorithms analyze patterns and trends in health data to identify potential risks and predict the likelihood of disease development. This capability facilitates early interventions, moving healthcare towards a proactive and preventive model (Topol, 2019).

Wearables play a crucial role in promoting a healthier lifestyle. By tracking physical activity, sleep patterns, and nutrition, wearables provide users with comprehensive insights into their daily habits. This awareness encourages positive behavioral changes, fostering healthier lifestyles and preventing the onset or progression of chronic diseases (Patel et al., 2015). Wearables contribute to preventive care by enabling early detection of health abnormalities. Continuous monitoring allows for the identification of subtle changes that may indicate the early stages of a disease. Timely interventions based on this early detection can prevent the progression of conditions and improve long-term health outcomes (Inan et al., 2017).

1.4. Challenges and considerations

While wearable technology holds great promise in transforming healthcare, several challenges and considerations must be addressed to ensure its widespread adoption and successful integration into existing healthcare systems (Chan et al., 2012). The continuous collection of health data by wearables raises concerns about the security and privacy of sensitive information. As wearables transmit and store data, there is a need for robust security measures to safeguard against unauthorized access. Ensuring data encryption and secure transmission protocols is essential to maintain the confidentiality of patient information (Majumder et al., 2017). Wearable technology must comply with existing data protection regulations, such as the Health Insurance Portability and Accountability Act (HIPAA) in the United States (Banerjee et al., 2018). Adhering to these regulations ensures that the use and storage of health data align with legal and ethical standards, fostering trust among users and healthcare providers (Topol, 2019). The seamless integration of wearable technology with existing healthcare systems remains a significant challenge. Interoperability issues arise when wearables use different data formats or communication protocols. Standardization efforts are essential to ensure that wearables can communicate effectively with electronic health records (EHRs) and other healthcare platforms (Ding et al., 2016). Healthcare professionals face challenges in incorporating wearable-generated data into their workflows. Time constraints and the need for additional training may hinder the seamless integration of wearables into clinical practices (Hilty et al., 2021). Addressing these challenges requires collaboration between technology developers and healthcare providers to design user-friendly interfaces and ensure minimal disruption to established workflows (Vegesna et al., 2019). The success of wearable technology in healthcare hinges on user engagement. Challenges related to user adoption include the need for user-friendly designs, clear communication of benefits, and addressing concerns about comfort and aesthetics. Strategies to enhance user engagement, such as gamification and personalized feedback, can contribute to sustained use (Patel et al., 2015). Adherence to wearable use can be influenced by various factors, including device accuracy, battery life, and comfort. Addressing these barriers requires ongoing improvements in technology, transparent communication about device limitations, and considering user preferences in the design of wearables. Overcoming these challenges is crucial for achieving sustained user adherence (Vegesna et al., 2019).

Ethical considerations surrounding wearables include ensuring informed consent for data collection and addressing questions of data ownership (Kerr et al., 2019). Users should be fully informed about how their data will be used, and there should be transparency about whether data will be shared with third parties. Establishing clear guidelines on data ownership and usage is paramount (Majumder et al., 2017). The use of algorithms in wearables for health predictions raises concerns about potential biases. Ensuring fairness and mitigating biases in algorithmic decision-making is essential to prevent unintended consequences, particularly in healthcare settings. Ethical considerations should guide the development and deployment of algorithms to ensure equitable outcomes (Topol, 2019).

1.5. Future prospects and advancements

Wearable technology in healthcare is poised for continuous evolution, with ongoing advancements promising to enhance capabilities, broaden applications, and redefine the landscape of personalized and proactive healthcare. The future of wearables involves the integration of more advanced biosensors capable of capturing a broader array of health data (Kim et al., 2019). Miniaturization and improved sensor technologies will enable wearables to measure biomarkers with greater precision, expanding their utility in diagnostics, disease monitoring, and treatment optimization (Gao et al., 2019). Future wearables are likely to integrate multimodal sensors, combining capabilities such as electrocardiography (ECG), photoplethysmography (PPG), and environmental sensors (Kim and Baek, 2023). This convergence of sensor modalities will provide a more comprehensive and contextualized view of an individual's health, enabling more accurate and holistic health assessments (Topol, 2019). The integration of advanced data analytics and artificial intelligence (AI) algorithms will elevate wearables to predictive tools. These algorithms can analyze vast datasets to identify patterns, predict health trends, and provide personalized recommendations for disease prevention and management. The synergy between wearables and AI will drive a paradigm shift towards proactive and predictive healthcare (Topol, 2019). Edge computing, where data is processed closer to the source (i.e., the wearable device), will enable real-time analytics. This reduces latency in data transmission, allowing wearables to provide immediate insights. The incorporation of edge computing in wearables enhances their capabilities for continuous monitoring and rapid decision support (Sharma & Conner, 2019).

The future of wearables extends beyond monitoring to therapeutic applications. Wearables equipped with features such as transcutaneous electrical nerve stimulation (TENS) or drug delivery mechanisms could offer non-invasive and personalized therapeutic interventions. This expansion of functionality transforms wearables into active agents in managing various health conditions (Topol, 2019). Wearables will play a central role in the integration of telemedicine platforms. As remote healthcare delivery becomes more prevalent, wearables will serve as the bridge connecting individuals to healthcare professionals. This integration will enhance the scope of virtual consultations, diagnostics, and continuous monitoring, fostering a more accessible and patient-centric healthcare model (Elsden et al., 2020). Future wearables will prioritize user-centric design to enhance comfort, aesthetics, and overall user experience. Innovations in materials, form factors, and customization options will contribute to wearables that seamlessly integrate into individuals' lifestyles, promoting sustained use and adherence (Patel et al., 2015). Collaboration between technology developers and fashion designers will result in wearables that are not only functional but also stylish. The fusion of fashion and technology will contribute to wearables being accepted as everyday accessories, reducing stigma and increasing societal acceptance of continuous health monitoring (Dunn, 2018).

1.6. Ethical considerations and societal implications

As wearable technology becomes more integrated into healthcare, it brings forth a myriad of ethical considerations and societal implications that need careful examination. The continuous monitoring and collection of health data by wearables raise significant privacy concerns. It is crucial to establish robust measures to protect individual health information from unauthorized access, ensuring that sensitive data is not exploited or misused. Ethical considerations dictate the need for transparency in data handling practices and adherence to data protection regulations (Majumder et al., 2017). Obtaining informed consent is critical in addressing privacy concerns. Wearable users should be fully informed about how their health data will be used, who will have access to it, and for what purposes. The consent process should be transparent, ensuring that individuals are empowered to make informed decisions about sharing their health information (Topol, 2019). The adoption of wearable technology in healthcare should be mindful of potential disparities related to socioeconomic factors. Ensuring equitable access to wearables and associated healthcare services is essential to prevent the exacerbation of existing health inequalities. Ethical considerations require proactive efforts to minimize disparities and promote inclusive healthcare (Vegesna et al., 2019). The concept of a digital divide extends to the adoption of wearable technology. Ethical considerations involve addressing barriers such as technological literacy, access to reliable internet connectivity, and affordability. Strategies should be in place to bridge the technological gap, ensuring that wearable healthcare solutions are accessible to diverse populations (Elsden et al., 2020). As wearables provide individuals with continuous health insights, ethical considerations revolve around maintaining user autonomy in health decisions. It is crucial to strike a balance between providing information for informed decision-making and respecting individual choices. Users should have the agency to interpret and act upon their health data based on personal preferences and values (Patel et al., 2015). Ethical considerations include avoiding overmedicalization, where continuous monitoring may lead to unnecessary interventions or medicalization of normal variations. Striking a balance between health surveillance and respecting the natural variability of health is crucial to prevent undue stress and interventions, ensuring that wearables contribute positively to well-being without causing unnecessary medicalization (Topol, 2019).

The use of wearables to continuously monitor health conditions raises ethical concerns related to potential stigmatization. Individuals wearing health-monitoring devices may face societal judgment or discrimination. Ethical considerations include strategies to mitigate stigma, educate the public, and foster a culture of acceptance and support for those using wearables for health management (Dunn, 2018). Ethical considerations extend to the societal implications of sharing health data on a large scale. Public attitudes towards data sharing, consent for research purposes, and the potential impact on insurance or employment must be carefully navigated. Striking a balance between advancing research and protecting individual rights is essential for responsible use of health data (Majumder et al., 2017).

2. Conclusion

The integration of wearable technology into healthcare has ushered in a transformative era, offering unprecedented opportunities to enhance patient outcomes and personalize treatments. This paper has explored the multifaceted role of wearable technology in healthcare, focusing on its impact on patient monitoring, healthcare outcomes, challenges, future prospects, and ethical considerations. In the exploration of patient monitoring, we delved into how wearables facilitate continuous health tracking, remote patient monitoring, and the management of chronic diseases. Real-time monitoring of vital signs, early detection of health abnormalities, and the ability to reduce hospital readmissions showcase the potential of wearables to revolutionize patient care. The discussion on healthcare outcomes highlighted how wearables contribute to improved patient engagement, personalized healthcare, and positive shifts in preventive care approaches. Empowering patients with access to health data, facilitating proactive health management, and tailoring treatment plans based on individual health data underscore the user-centric and outcome-driven nature of wearable technology. However, the adoption of wearable technology in healthcare comes with its share of challenges. Privacy concerns, integration with existing healthcare systems, user adoption, and ethical considerations require meticulous attention to ensure responsible and equitable deployment. Balancing the benefits of wearables with ethical considerations is paramount to building trust among users and fostering a sustainable healthcare ecosystem. Looking ahead, the future of wearable technology holds exciting prospects. Advancements in sensor technologies, data analytics, and artificial intelligence promise to elevate wearables to predictive tools with therapeutic applications. The integration of wearables with telemedicine platforms and a focus on user-centric design will further broaden their impact on healthcare delivery. Yet, as we embrace the potential of wearables, ethical considerations and societal implications must guide their deployment. Privacy safeguards, equitable access, respect for individual autonomy, and efforts to mitigate stigmatization are essential to ensure the responsible and inclusive integration of wearables into healthcare. Wearable technology stands at the forefront of healthcare innovation, offering a paradigm shift towards personalized, proactive, and patient-centric healthcare. As we navigate the complexities of implementation, it is imperative to uphold ethical standards, prioritize user needs, and foster a collaborative approach between technology developers, healthcare professionals, and individuals. The journey towards realizing the full potential of wearable technology in healthcare is a dynamic and evolving one, promising a future where health is not just monitored but actively managed, empowering individuals to lead healthier lives.

Compliance with ethical standards

Disclosure of conflict of interest

I declare that I have no conflicts of interest, financial or otherwise.

References

[1] Baig, M. M., GholamHosseini, H., & Connolly, M. J. (2015). Mobile healthcare applications: system design review, critical issues and challenges. *Australasian physical & engineering sciences in medicine*, *38*, 23-38.

[2] Banerjee, S., Hemphill, T., & Longstreet, P. (2018). Wearable devices and healthcare: Data sharing and privacy. *The Information Society*, *34*(1), 49-57.

[3] Bhatt, V., & Chakraborty, S. (2023). Improving service engagement in healthcare through internet of things based healthcare systems. *Journal of Science and Technology Policy Management*, *14*(1), 53-73.

[4] Bonato, P. (2019). "Wearable Sensors and Systems." *IEEE Engineering in Medicine and Biology Magazine, 38*(4), 42-50.

[5] Catalano, P., Gao, W., Tavazzi, L., Maggioni, A. P., Böhm, M., Hill, J. A., ... & Lam, C. S. P. (2020). "Chronic Medication Use in Heart Failure with Reduced and Preserved Ejection Fraction." Circulation: Heart Failure, 13(7), e006846.

[6] Chan, M., Estève, D., Fourniols, J. Y., Escriba, C., & Campo, E. (2012). Smart wearable systems: Current status and future challenges. *Artificial intelligence in medicine*, *56*(3), 137-156.

[7] Chan, M., Estève, D., Fourniols, J. Y., Escriba, C., & Campo, E. (2012). Smart wearable systems: Current status and future challenges. *Artificial intelligence in medicine*, *56*(3), 137-156.

[8] Chen, K., Cheng, Q., Ding, X., Zhang, Y., & Chen, S. (2018). "Wearable Sensor-Based Human Activity Recognition Algorithm with Enhanced Generalization Performance." Sensors, 18(12), 4177.

[9] Cho, J. H., Lee, H. C., Lim, D. J., Kwon, H. S., & Yoon, K. H. (2018). "Mobile Communication Using a Mobile Phone with a Glucometer for Glucose Control in Type 2 Patients with Diabetes: As Effective as an Internet-based Glucometer." Journal of Korean Medical Science, 33(22), e162.

[10] Dias, D., & Paulo Silva Cunha, J. (2018). Wearable health devices—vital sign monitoring, systems and technologies. *Sensors*, *18*(8), 2414.

[11] Ding, X. R., Zhang, Y. T., & Liu, J. (2016). "Wearable Monitoring Systems." Springer Science+Business Media.

[12] Dolan, B., Teixeira, T., Ferreira, D., & Rodrigues, P. (2018). "Wearable Health Devices—Vital Sign Monitoring, Systems and Technologies." Sensors, 18(8), 2414.

[13] Dorfman, R., Khayat, Z., Sieminowski, T., Golden, B., & Lyons, R. (2013). Application of personalized medicine to chronic disease: a feasibility assessment. *Clinical and translational medicine*, *2*(1), 1-11.

[14] Dunn, J. (2018). "Wearables and the medical revolution." Per Med, 15(5), 429-448.

[15] Elsden, C., Nissen, B., Garbett, A., Chatting, D., & Kirk, D. (2020)."Metadating: Exploring the Romance and Future of Personal Data." Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, 1-13.

[16] Gao, S., Tang, G., Hua, D., Xiong, R., Han, J., Jiang, S., ... & Huang, C. (2019). Stimuli-responsive bio-based polymeric systems and their applications. *Journal of Materials Chemistry B*, *7*(5), 709-729.

[17] Hilty, D. M., Armstrong, C. M., Edwards-Stewart, A., Gentry, M. T., Luxton, D. D., & Krupinski, E. A. (2021). Sensor, wearable, and remote patient monitoring competencies for clinical care and training: scoping review. *Journal of Technology in Behavioral Science*, *6*, 252-277.

[18] Inan, O. T., Migeotte, P. F., Park, K. S., Etemadi, M., Tavakolian, K., Casanella, R., ... & Ballinger, J. (2017)."In vivo wrist-based blood pressure monitoring using a wearable pressure sensor." Scientific Reports, 7(1), 1-11.

[19] Kerr, D., Butler-Henderson, K., & Sahama, T. (2019). Security, privacy, and ownership issues with the use of wearable health technologies. In *Cyber Law, Privacy, and Security: Concepts, Methodologies, Tools, and Applications* (pp. 1629-1644). IGI Global.

[20] Kim, J., Campbell, A. S., de Ávila, B. E. F., & Wang, J. (2019). Wearable biosensors for healthcare monitoring. *Nature biotechnology*, *37*(4), 389-406.

[21] Kim, K. B., & Baek, H. J. (2023). Photoplethysmography in wearable devices: a comprehensive review of technological advances, current challenges, and future directions. *Electronics*, *12*(13), 2923.

[22] Kroll, R. R. (2019). "Digital Medicine: Wearables and Implantables." Journal of Personalized Medicine, 9(4), 41.

[23] Lee, J. G., Lee, B., & Choe, E. K. (2023). Decorative, Evocative, and Uncanny: Reactions on Ambient-to-Disruptive Health Notifications via Plant-Mimicking Shape-Changing Interfaces. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (pp. 1-16).

[24] Lukowicz, P., Ward, J. A., Junker, H., Stäger, M., & Tröster, G. (2004). "Recognizing workshop activity using body-worn microphones and accelerometers." Ambient Intelligence, 3305, 55-66.

[25] Majumder, S., Mondal, T., Deen, M. J., & Wearable Health Informatics. (2017). "A Systematic Review of Wearable Sensors and IoT-Based Monitoring Applications for Older Adults—A Focus on Ageing Population and Health Management." Sensors, 17(6), 130

[26] Patel, M. S., Asch, D. A., & Volpp, K. G. (2015). "Wearable Devices as Facilitators, Not Drivers, of Health Behavior Change." JAMA, 313(5), 459-460.

[27] Rothman, M. J., Rothman, S. I., & Beals IV, J. (2013). Development and validation of a continuous measure of patient condition using the electronic medical record. *Journal of biomedical informatics*, *46*(5), 837-848.

[28] Rumschlag, T., Bishu, R., Oetgen, W. J., & Blair, J. E. (2018). "The Role of Wearable Devices in Continuous Monitoring of Patients with Heart Failure: A Systematic Review." American Journal of Therapeutics, 25(2), e218-e222.

[29] Sharma, D., & Conner, D. A. (2019). "Wearable Devices for Heart Monitoring." Journal of Cardiovascular Translational Research, 12(2), 105-114.

[30] Steinhubl, S. R., Muse, E. D., & Topol, E. J. (2015). "The emerging field of mobile health." Science Translational Medicine, 7 (283), 283rv3.

[31] Swan, M. (2012). "Sensor mania! The Internet of Things, wearable computing, objective metrics, and the quantified self 2.0." Journal of Sensor and Actuator Networks, 1 (3), 217-253.

[32] Topol, E. J. (2019). "High-Performance Medicine: The Convergence of Human and Artificial Intelligence." Nature Medicine, 25(1), 44-56.

[33] Vegesna, A., Tran, M., Angelaccio, M., & Arcona, S. (2019). "Remote Patient Monitoring via Non-Invasive Digital Technologies: A Systematic Review." Telemedicine and e-Health, 25(12), 1093-1100.

[34] Vijayan, V., Connolly, J. P., Condell, J., McKelvey, N., & Gardiner, P. (2021). Review of wearable devices and data collection considerations for connected health. *Sensors*, *21*(16), 5589.

[35] Wang, R., Blackburn, G., Desai, M., Phelan, D., Gillinov, L., Houghtaling, P., ... & Gillinov, M. (2015). "Accuracy of Wrist-Worn Heart Rate Monitors." JAMA Cardiology, 2(1), 104-106.