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SMART WEARABLES AS EARLY WARNING SYSTEMS FOR SEDENTARY-INDUCED HEALTH RISKS IN YOUTH: A SCOPING REVIEW OF SPORT AND HEALTH PERSPECTIVES

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Abstract

Lack of physical activity and increasing sedentary lifestyles among adolescents and young adults pose significant health risks, including metabolic and cardiovascular disorders. Wearable biosensor technologies such as smartwatches and fitness trackers have the potential to serve as early warning systems for health risks associated with sedentary behavior. This scoping review aims to map the trends, effectiveness, and challenges of using wearables to promote physical activity and monitor vital signs in young populations. A literature search was conducted across six leading databases, yielding 1,901 articles, with 24 studies meeting the inclusion criteria. Findings were grouped into six main themes: (1) user compliance and psychological factors, (2) impact on physical activity and sedentary behavior, (3) vital sign and biomarker monitoring, (4) sensor validity and reliability, (5) injury prevention and athlete performance enhancement, and (6) clinical implementation, ethics, and technology integration. Results show that wearables are capable of increasing physical activity, predicting health status through heart rate variability (HRV), and supporting decision-making in sports and clinics. However, long-term success is highly dependent on system integration, sensor validation, and sustainable real-world use. This study provides a scientific basis and strategic recommendations for the development of wearable-based health technology interventions in Indonesia.

Keywords: *wearable biosensors, physical activity, sedentary behavior, young adults, vitalsigns*

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Introduction

Physical inactivity is a major global public health challenge, contributing to the increasing prevalence of noncommunicable diseases such as cardiovascular disease, type 2 diabetes, and obesity. The World Health Organization (WHO) estimates that more than 80% of adolescents and young adults worldwide do not meet the minimum recommended physical activity of at least 150 minutes of moderate-intensity activity per week. This situation underscores the need for innovative health promotion strategies, especially for the young adult age group (18–35 years), which is in a transition phase towards lifestyle independence and long-term health decision-making. A recent study among 6,975 undergraduate students in Saudi Arabia found that approximately 58% spent at least seven hours per day in sedentary activities, with men accumulating more sitting time than women. Physiologically, sedentary behavior in young adults has been associated with an unfavorable vital sign profile. Evidence from Spanish college students suggests that greater daily sitting is correlated with higher resting heart rate and higher stress levels.

As technology advances, wearable biosensors have emerged as promising tools in health monitoring and promoting healthy behaviors. Devices such as smartwatches, fitness trackers, and smart rings are capable of collecting real-time biometric data, including step count, heart rate, sleep patterns, and calories burned. The ability to provide instant and objective feedback on physical activity levels can empower individuals to be more aware of their behavior and motivated to make positive changes. Wearable-based interventions have shown potential to increase user engagement in physical activity through mechanisms such as goal setting, self-monitoring, and behavioral reinforcement.

However, scientific evidence regarding the effectiveness and working mechanisms of wearable biosensors in young adults is still scattered and varied. Some studies show positive results in increasing the number of steps and duration of physical activity. In contrast, others report barriers related to long-term adoption, user motivation, and device integration with lifestyle. Therefore, a systematic and comprehensive literature mapping is needed to identify trends, scope, and research gaps related to the role of wearable biosensors in promoting physical activity in young adults so that it can provide guidance for future public health interventions and technology development.

Methods

We searched electronic databases from Springer Link, PubMed, Taylor & Francis, Research Gate, Science Direct, and these databases were selected to provide a large enough range for data retrieval across contexts and are recognized as top research databases. The following keyword combinations were used: ("wearable biosensors" OR "fitness tracker" OR "smartwatch" OR "activity monitor") AND ("physical activity" OR "exercise") AND ("young adults" OR "emerging adults" OR "youth") AND ("health") AND ("Sedentary"). This scoping review was structured following the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews) guidelines as described by Tricco et al. (2018). (Tricco et al., 2018) .

These terms encompass a range of wearable biosensors that can significantly motivate students to engage in physical activity through competition and personalized feedback, the effectiveness of which may vary based on individual motivational profiles and the context of use. Reference lists were searched for additional studies eligible for inclusion.

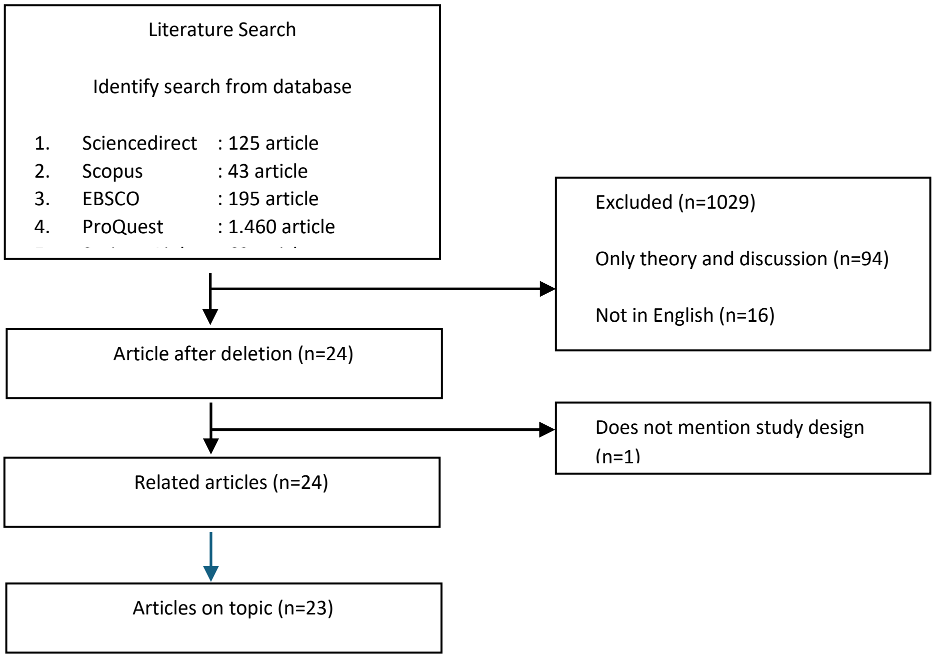

Figure 1. PRISMA-ScR

Studies were considered for inclusion if they were (1) published in a peer-reviewed journal; (2) published between 2021 and 2025; (3) open access; (4) article research; (5) investigating how wearable technology could capture changes in vital signs associated with the transition from sedentary to active. Abstract review identified additional studies that failed to meet the inclusion criteria, leaving 25 studies. These studies were read, and one was excluded for not meeting one or more inclusion criteria. The following twenty-four papers were used for this review.

Results

Table 1. Analysis matrix in the literature

Author, year	Title	Objective	Study design, method, and participants	Results
(Faust et al., 2024)	Passive sensing of smartphone use, physical activity and sedentary behavior among adolescents and young adults during the COVID-19 pandemic	The primary objective of this study was to evaluate the association between physical activity or sedentary behavior and smartphone screen time or specific smartphone app use among adolescents and young adults during the COVID-19 pandemic. This study specifically used passively perceived data to test these associations.	• This study used a micro-longitudinal observational study design. • The study involved adolescents and young adults, with a total of 125 participants. • Data Collection: Participants wore the ActivPAL4 micro activity monitor to measure physical activity and	Smartphone use in general is associated with decreased physical activity, especially when used for apps like Instagram, YouTube, and TikTok. However, the relationship between smartphone use and sedentary behavior is not always consistent. The type of app influences the impact—messaging apps tend to increase

			sedentary behavior. • Smartphone and app usage data is collected via screen recordings for iPhone users and a dedicated smartphone app (PAStime) for Android users.	sitting time, while Instagram can actually decrease it.
(Wu et al., 2024)	Wearable device adherence among insufficiently-active young adults is independent of identity and motivation for physical activity	investigated the relationship between psychological factors and adherence to wearable device use among young adults. Specifically, it sought to evaluate whether sport identity and motivation for physical activity were associated with how consistently young adults wore a physical activity monitor.	• This study uses a cross-sectional research design approach. • Ambulatory Physical Activity Assessment: Physical activity was assessed using the ActiGraph WGT3x-BT accelerometer. • Practice Identity Assessment: Practice identity was measured using the 9-item Practice Identity Scale (EIS). • Contextual Motivation Assessment was assessed using the 23-item Behavioral Regulation in Exercise Questionnaire-2 (BREQ-2) and an additional four-item integrated motivation scale. • The combined analytical sample consisted of 271 young adults.	This study found that young adults generally showed high adherence to wearable devices. Importantly, psychological factors such as identity and exercise motivation appeared to have minimal direct influence on adherence, suggesting that situational factors or external instructions may be more dominant. Demographic variables also had little impact, with the notable exceptions of age and the timing of data collection relative to the pandemic.
(Utesch et al., 2022)	Self-tracking of daily physical activity using a fitness tracker and the effect of the 10,000 steps goal	The primary aim of this outpatient assessment study was to empirically evaluate the effects of activity self-tracking on daily physical activity (PA) behavior. This evaluation specifically considered self-tracking both alone and in combination with daily step goals. The study was conducted as a	• This study was conducted as a 6-week randomized controlled parallel group trial, using an outpatient assessment approach. • All groups received a commercially available, wrist-worn fitness tracker (Fitbit Flex 2) and a connected	This study found that neither self-tracking with a fitness tracker nor an additional 10,000-step goal significantly increased objective physical activity levels or changed their trajectories over a 6-week period. While some effects were observed on self-

		randomized controlled parallel group trial.	smartphone app to track their PA (daily step count). Except for the control group • The final sample consisted of 150 participants, with a mean age of 24.66 years (SD = 4.75)	reported PA, these were not consistent with objective measures, highlighting the importance of considering individual differences in future interventions.
(Grosicki et al., 2022)	Self - recorded heart rate variability profiles are associated with health and lifestyle markers in young adults	The primary aim of this study was to measure the association between self-recorded heart rate variability (HRV) profiles and various health and lifestyle markers in young adults.	• Cross-Section Observational Study: This is a cross-sectional study involving a 7-day observation period followed by laboratory testing. • • final sample of 40 individuals, with equal numbers of males and females • Self-Recording: HRV was self-recorded for seven days using a chest strap (H10, Polar Electro) paired with a free smartphone app (Elite HRV) • (Physical Activity and Sleep) wore an ActiGraph GT9X accelerometer on their non-dominant wrist continuously for seven days.	This study found that higher or more stable supine and standing HRV values were generally associated with superior health and lifestyle markers in young adults, for both men and women. While aerobic fitness (VO_2peak) was a significant driver of many of these associations, some relationships persisted independently of fitness, particularly for Cf-PWV in men and a range of cardiovascular and metabolic parameters in women. These findings suggest the potential utility of self-recorded ultra-short HRV as a tool for health-promoting behavior modification in young adults.
(Migueles et al., 2022)	Equivalency of four research - grades movement sensors to assess movement behaviors and its implications for population surveillance	The primary objective of this study was to investigate the agreement of movement behavior outcomes when assessed using four different research-grade activity monitors: Movisens Move4, ActiGraph GT3X+, GeneActiv, and Axivity AX3.	• This study uses an observational study method. • The research sample consisted of 23 respondents • Activity Monitoring: Participants wore four research-grade activity monitors simultaneously on their non-dominant wrist for seven days: Movisens Move 4, ActiGraph GT3X+, GeneActiv, and Axivity AX3	This study demonstrated high inter-instrument reliability among the Movisens Move4, ActiGraph GT3X+, GeneActiv, and Axivity AX3 when their raw data were processed identically. While some minor differences existed, particularly with GeneActiv for sleep, sedentary time, and MVPA, overall agreement was strong, supporting the

				potential of these monitors in population-based physical activity and sleep monitoring.
(Preatoni et al., 2022)	The Use of Wearable Sensors for Preventing, Assessing, and Informing Recovery from Sport-Related Musculoskeletal Injuries.	Wearable technology is a solution for collecting biomedical data directly in the field efficiently and without disrupting athlete activities. Its purpose is to support the prevention and recovery of sports-related musculoskeletal injuries.	• This study used a *systematic scoping review design* based on the PRISMA-ScR guidelines. • This study did not involve direct participants, but analyzed 48 relevant articles from PubMed, Scopus, and Web of Science. • Inclusion criteria included studies evaluating the use of wearable sensors for the prevention, assessment, and recovery of sports injuries. • Articles were selected and qualitatively analyzed to identify trends, benefits, and limitations of wearable technology in the context of sports injuries.	Wearable sensors have the potential to aid in the prevention and rehabilitation of sports injuries, but much of the research is preliminary, lacks validation, and has not been fully implemented in the field.
Becking - Verhaar (2023)	Continuous Vital Signs Monitoring with a Wireless Device on a General Ward: A Survey to Explore Nurses' Experiences in a Post-Implementation Period	The use of wireless to monitor vital signs aims to improve patient safety by detecting early changes in patient conditions, optimizing the frequency of manual measurements, increasing patient comfort. The use of wireless is useful for improving the quality of service in general wards.	• This study used a cross-sectional survey design. • This research was conducted using a digital survey consisting of 10 items, including closed and open questions. • The survey was developed by 7 experts (consisting of innovation experts, research nurses, and doctors). • The survey was conducted using SurveyMonkey and was available from July 18 to August 23,	Vital signs monitoring with wireless devices can detect and provide rapid intervention to deteriorating patients, thereby improving patient safety. However, the challenge is the difficulty of connecting patients to the system device which interferes with the effectiveness of using this technology.

			2019. • Data analysis used descriptive statistics for closed questions and thematic analysis for open questions. • Sampling technique: purposive sampling • Participants: 111 nurses, namely vocational nurses and registered nurses working in three general wards of a tertiary university hospital in the Netherlands. • Inclusion criteria: nurses with direct experience in using the ViSi Mobile device. • Exclusion criteria: senior nurses, nursing assistants, temporary workers, and interns. • Number of respondents: 58 nurses (response rate 51.3%).	
Wu (2024)	Wearable device adherence among insufficiently-active young adults is independent of identity and motivation for physical activity	The use of wearable devices for physical activity monitoring in young adults who are less physically active, and the influence of psychological factors such as self-identity as a physically active individual and motivation for physical activity on compliance.	• This study is a secondary data analysis of two physical activity intervention projects conducted before and after the declaration of the COVID-19 pandemic. • Participants wore the ActiGraph GT3X+ accelerometer on their waist for 7 consecutive days. • Data were analyzed using multiple linear regression, using R software. • 271 young adults (18–29 years) who were physically inactive. • Taken from two	Wearable usage among young adults who are less physically active is quite high. However, no significant relationship was found between identity as an active sports individual or motivation for physical activity with the duration of device use. Factors that increase are older age and lower levels of integrated regulation

			studies: before and after the COVID-19 pandemic.	
Smuck et al. (2021)	The emerging clinical role of wearables: factors for successful implementation in healthcare	Examining the integration of wearable technology in clinical settings and the potential benefits and challenges.	• This study uses a literature-based narrative review design to evaluate the integration of wearable devices in the healthcare system. • This article does not involve participants directly, but rather analyzes and synthesizes findings from a variety of empirical studies, industry reports, and policy documents. • Data were collected through a systematic search of the literature related to the adoption of wearable technology in clinical settings. • The focus of the study includes aspects of data accuracy, user compliance, clinical relevance, system interoperability, and implementation challenges such as integration with EHR and patient data privacy.	Key factors identified included data accuracy, user compliance, clinical relevance, and integration into the electronic medical record.
Liu (2020)	Recent Progress in Flexible Wearable Sensors for Vital Sign Monitoring	The demand for wearable devices is increasing rapidly due to their ability to monitor vital signs in real-time, but their development faces challenges such as accuracy, comfort, and power consumption. Flexible sensors based on novel materials are a potential solution to improve signal quality and user comfort.	• This study is a narrative literature review that discusses the latest developments in wearable flexible sensors for vital signs monitoring. • This study collects and synthesizes findings from recent scientific publications related to flexible sensor technologies,	Recent advances in wearable flexible sensors for vital signs monitoring such as electrophysiological signals, body temperature, and respiratory rate, both implantable and non-implantable. The use of advanced materials such as graphene, flexible metals, and conductive textiles demonstrates improved

			including electrophysiological sensors (ECG, EEG, EMG), body temperature sensors, and respiratory rate sensors. • There were no direct human participants as this was a review study. The main focus was on various existing wearable devices and prototypes tested in previous studies, both implantable and non -implantable .	signal quality, comfort, and potential for integration in long-term medical applications.
Dunker (2021)	smart Wearables for Cardiac Monitoring—Real-World Use beyond Atrial Fibrillation	The development of wearable technology can be used for the diagnosis and management of cardiovascular disease. These devices are complex tools and have the potential to detect and support the treatment of heart disease, including heart rhythms other than atrial fibrillation. The role of the health care provider is to evaluate the accuracy of these devices.	• This research is a narrative review study based on real-world evidence. • Analysis of various studies and reports on the use of smart wearables in monitoring cardiac conditions, especially outside atrial fibrillation, such as other arrhythmias, heart failure, and sleep apnea. • It does not involve participants directly because it is a literature study, but discusses the results and implementation of wearable use in patients with various cardiovascular conditions. • Data sources include clinical studies, observations of use in the general population, and evaluations of technology integration within health care systems.	Smart wearables have been effective in monitoring a variety of cardiac conditions beyond atrial fibrillation, such as arrhythmias, heart failure, and sleep apnea. While promising, further clinical validation and careful integration into healthcare systems are needed.
Meng	Application of	Nervous system diseases	• This study is a	Biosensors such as

(2024)	advanced biosensors in nervous system diseases	can be diagnosed using advanced biosensors that can monitor and rehabilitate neurological diseases. Devices such as brain-computer interfaces and wearable sensors are already widely used.	systematic literature review study that discusses the application of advanced biosensors in the diagnosis and rehabilitation of nervous system diseases. • It does not involve participants directly because it is a review study. • The data sources were collected from various scientific publications regarding the use of **brain-computer interfaces** and **wearable biosensors** in neurological diseases such as Parkinson's, stroke, and epilepsy. • Focus on cutting-edge sensors that can capture neural signals in real-time with high accuracy and enable biometric data-based neurological interventions.	brain-computer interfaces and wearable sensors are widely used to monitor and rehabilitate neurological diseases. This use is very accurate and fast in diagnosing
Ali & Iqbal (2025)	Disconnected connections: The impact of technology on adolescent emotions and behavior	Technoference is associated with increased internalizing, externalizing, and decreased prosocial behavior problems in adolescents. The negative impacts on family dynamics and adolescent mental health to design healthier interventions.	• This study uses a correlational quantitative design with a survey approach. • This study involved adolescents and their parents as the main participants, from various family backgrounds. • Data collection was conducted using a questionnaire that measures the level of technoference, internalizing-externalizing emotions, and prosocial behavior.	Technoference is related to parents and adolescents with increased internalizing and externalizing behavior. Adolescents have a stronger and more consistent influence than parents. High digital use is also correlated with negative behavior and decreased positive interactions within the family.

			• The instruments were filled out independently by adolescents and parents, and analyzed to see the influence of technology use on emotional and behavioral dynamics.	
Mateo-Orcajada (2024)	Physical Activity, Body Composition, and Fitness Variables in Adolescents After Periods of Mandatory, Promoted or Nonmandatory, Nonpromoted Use of Step Tracker Mobile Apps: Randomized Controlled Trial	Teenagers are becoming less active due to sedentary lifestyles and screen time. This study examines whether mandatory use of a step-tracking app in class can shape long-term healthy walking habits.	• This study used a randomized controlled trial design. • The study involved high school students as participants who were divided into three groups: mandatory use, voluntary use, and control group. • The intervention was carried out using a step tracking application during physical education class periods. • Physical activity was measured by the number of daily steps during and after the intervention; the effects were compared between groups to evaluate short-term effects and long-term habits.	that mandatory use of a step-tracking app in physical education classes increased students' daily step count during the intervention. However, after the intervention was stopped, the increase was not fully maintained. The type of app used, biological maturity level, and gender did not significantly affect long-term walking habits.
Thank you (2023)	Machine Learning Approach for Pitch Type Classification Based on Pelvis and Trunk Kinematics Captured with Wearable Sensors	Wearable technology enables detailed monitoring of pitching mechanics in baseball, which is essential for improving performance and preventing injuries. This study develops a method for classifying pitch types based on kinematic data from body-worn sensors, providing accurate, real-time feedback to players.	• Type of research: Experimental • Approach: Biomechanical data-based machine learning classification • Of the 24 pitchers who initially participated in the measurements, 19 pitchers were included in the study (age 18.5 ± 3.7 years, height 178.3 ± 11.1 m, weight 71.9 ± 18.3 kg, experience 7.3 ±	A total of 353 pitches from 19 pitchers were analyzed using kinematic data from wearable sensors. In the binary classification (fastball vs. not fastball), the Naive Bayes algorithm produced the best accuracy of 71%. Meanwhile, for the classification of three types of pitches (fastball, curveball, change-up), the

			3.7 years) • The pitching motion was recorded using the PITCHPERFECT system (PITCHPERFECT, Breda, The Netherlands) consisting of two synchronized 3-DOF IMUs (Gyroscope ±2000 (°/s)) as shown in	Random Forest algorithm performed best with an average accuracy of 61.3%, with fastball being the most accurately classified (73.9%).
Ridgers (2021)	Effect of commercial wearables and digital behavior change resources on the physical activity of adolescents attending schools in socio-economically disadvantaged areas: the RAW-PA cluster-randomized controlled trial	evaluate the short-term and long-term effects of the use of wearable devices combined with digital resources for behavioral change on the physical activity levels of school-going adolescents in the area.	• This study used a cluster-randomised controlled trial design . • This study involved adolescents attending schools in areas with low socioeconomic status . • A total of 298 students from 18 secondary schools in Victoria, Australia. • The intervention group received a wearable device (Fitbit Flex) and access to digital behavior change resources for 12 weeks, while the control group received no intervention. • Physical activity was measured using an ActiGraph GT3X+ accelerometer monitor worn on the waist for 7 full days at baseline, end of intervention, and 6-month follow-up.	The use of wearable devices combined with digital interventions successfully increased physical activity in adolescents in the short term, but the effects tended to decline over time. In addition, active participation and involvement in the program greatly influenced the success of increasing physical activity.
Zhang (2025)	Using a Consumer Wearable Activity Monitoring	describes the data collection process and initial results of physical activity and sleep measurements using	• This study used a longitudinal cohort study design. • The study involved adolescents who	Fitbit devices were successfully used to collect physical activity and sleep data in adolescents with high

	Device to Study Physical Activity and Sleep Among Adolescents in Project Viva: Cohort Study	Fitbit devices in a group of adolescents in the Project Viva cohort project.	were participants in Project Viva, a community-based birth cohort in the United States. • Data collection was conducted using a Fitbit wearable device to objectively monitor physical activity and sleep. • Teenagers were asked to wear the device for several consecutive days, and data was collected on daily steps, sleep time, and duration of physical activity.	levels of compliance throughout the monitoring period.
Seshadri (2024)	Wearable Devices and Digital Biomarkers for Optimizing Training Tolerances and Athlete Performance: A Case Study of a National Collegiate Athletic Association Division III Soccer Team over a One-Year Period	Injuries are high in Division III athletes due to limited resources, while wearable technology has been shown to be effective in monitoring training load and preventing injuries. This study analyzed data from a DIII football team to optimize performance and prevent injuries.	• This research is a one-year longitudinal case study. • This study was conducted on NCAA Division III men's soccer teams in the United States. • Data collection was conducted using wearable devices to monitor training load and digital biomarkers throughout the competitive season. • Data is collected in real-time regarding training intensity, duration, frequency, and players' physiological indicators. • Participants consisted of all members of a soccer team (number not explicitly stated), who were monitored during the preseason, competitive season, and offseason.	Training load monitoring with wearable devices allows identification of physical load patterns throughout the season, including increases in load during the pre-season and fluctuations during the competitive season. This data helps coaches adjust training intensity to reduce the risk of injury and maintain player performance.
Lang (2025)	Application of Wearable Insole Sensors	If bone stress injuries, such as fatigue tibial fractures, often occur in	• This research is a laboratory experiment based on	The combined TCN and Transformer model showed high accuracy,

	in In-Place Running: Estimating Lower Limb Load Using Machine Learning	runners and are difficult to detect early, a wearable insole-based biomechanical load monitoring system is needed that can accurately predict ground reaction forces and bone forces using machine learning models.	wearable sensors and biomechanical modeling. • Our study combines wearable technology and machine learning methods for data collection and load estimation on the lower limbs during exercise. • Number of participants: 9 healthy volunteers • Gender: 7 males, 2 females	efficiency, and stability in predicting vGRF and TBF in real-time using wearable insoles, and can be used outside the laboratory due to its practical and portable nature. However, this model still needs further validation in real conditions and has limitations because not all biomechanical aspects can be detected only from insole pressure.
You (2025)	Preadolescent Children Using Real-Time Heart Rate During Moderate to Vigorous Physical Activity: A Feasibility Study	Evaluating the use of a chest heart rate sensor and the Connexx app to help children aged 9–12 years understand their heart rate data during intense physical activity.	• This research is a feasibility study with a simple experimental quantitative approach . • This study involved pre-adolescent children aged 9–12 years as the main participants. • Data collection was conducted using a chest-based heart rate sensor connected to the Connexx app to monitor heart rate in real-time during moderate-to-vigorous physical activity (MVPA). • Participants performed physical activities while viewing their heart rate zones on the app screen, with a focus on users' understanding of their physiological data .	The use of knowledge is relatively high. However, the increase in income, production, and market scale is still relatively low. The main factor that influences the training results is the suitability of the curriculum and CSR program, so it is recommended that training and program management be more tailored to the needs of the participants.

A total of 1,904 articles were obtained as literature from Sciencedirect, 125 articles, Scopus 43 articles, EBSCO 195 articles, ProQuest 1,460 articles, SpringerLink 62 articles, and Sage Journal 16 articles. After removing duplicates and searching the title-abstract, 24 articles met all inclusion criteria and were further analyzed. The findings cluster naturally into the following six main themes:

Theme 1: User Compliance & Psychological Factors (4 studies)

A study conducted by Wu et al (2024) examined the relationship between wearable device use and factors, specifically identity and motivation, in young adults who are physically inactive. The study results showed that adherence to the use of most wearable devices was independent of individual demographic characteristics, identity, and motivation.

In the study of Mateo-Orcajada et al (2024), it was stated that user compliance with the intervention (in this case, the use of a step tracker application) was greatly influenced by the conditions in which the intervention was implemented (mandatory/non-mandatory, promoted/not promoted). The lack of continued use after the removal of the mandate suggests that internal motivation for healthy walking habits may not have been formed, which is an important aspect of the factors important in long-term maintenance.

Physical activity increased initially in intervention respondents, but reliance on initial enthusiasm and personal engagement caused the effect to decline. This underscores the importance of environmental factors and ongoing support (Ridgers et al., 2021)

The very high level of compliance during monitoring suggests that with supportive study design and monitoring, wearables can be used consistently in young populations.

Theme 2 : Impact on Physical Activity & Sedentary Behavior (7 studies *)*

Faust et al. (2024) showed that the use of entertainment applications (TikTok, Instagram) was negatively correlated with physical activity. Meanwhile, Zahrt et al. (2023) showed that the mindset or perception of users towards “adequate physical activity” also influenced the success of wearables. The relationship between the two suggests that wearables can help control the negative impacts of digitalization, but it needs to be accompanied by psychological intervention or behavioral education so that users’ perceptions of activity become more positive.

Zhang et al. (2025) proved that wearables can be relied on to monitor adolescents' activities and sleep in the long term with a high level of compliance. Relevance: This study reinforces that wearables are not only an activity driver, but also an accurate long-term monitoring tool, especially when the user is guided properly.

Theme 3: Vital Signs & Health Biomarkers Monitoring (6 studies)

The six studies analyzed in this theme show that wearable biosensors play an increasingly important role in monitoring vital signs and health biomarkers, both in preventive and clinical contexts. The interrelationships between the studies can be understood through three main functional layers: early prediction of health risks, real-time clinical monitoring, and strengthening health system capacity through technology integration.

First, studies by Grosicki et al. (2022) and Liu et al. (2020) confirmed that wearables are capable of generating relevant non-invasive biomarker data, such as HRV, VO_2max , and respiratory rate. Self-recorded HRV was shown to be strongly correlated with various cardiometabolic indicators, even over ultra-short measurement durations. Meanwhile, advances in sensor materials such as graphene and conductive textiles provide increasingly high comfort and signal accuracy, opening up opportunities for long-term monitoring in everyday life.

Second, the clinical dimension is reinforced by findings from Becking-Verhaar (2023), Duncker et al. (2021), and Öztürk & Azizoğlu (2025). Becking-Verhaar showed how wireless device-based vital sign monitoring can accelerate the detection of deteriorating patient conditions in hospital wards, although ergonomic aspects and technical readiness of health workers remain challenges. In line with this, Duncker and team showed that wearables have been used in real-world settings to monitor conditions such as arrhythmia, sleep apnea, and heart failure—demonstrating strong diagnostic potential, provided they are accompanied by clinical validation and integration into electronic health records (EHR). The study from Öztürk & Azizoğlu adds a nursing perspective, where wearables support clinical decision-making and the safety of elderly patients, while highlighting the importance of technical training and privacy regulations.

Third, a study by Meng et al. (2024) broadens the scope of the theme by showing that advanced wearables and biosensors are now being used in the monitoring of nervous system diseases. The use of brain-computer interfaces and wearable sensors for the diagnosis and rehabilitation of neurological diseases strengthens the position of wearables as a cross-disciplinary precision health support tool.

From the relationship, it can be concluded that all studies complement each other in describing the potential of wearable biosensors as a tool for early detection, continuous monitoring, and strengthening the healthcare system. Integration between the sophistication of sensor technology, clinical context, and readiness for implementation is the primary key to encourage the adoption of this technology in real practice. In the future, the synergy between technological innovation and the readiness of the health care system will determine the success of wearables in contributing to disease prevention and improving the quality of life of the community at large.

Theme 4: Sensor Reliability & Validation (5 studies)

The validity and reliability of sensors are the main foundations of the successful implementation of wearable technology in health and physical activity monitoring. The five studies in this theme form a narrative that complements each other: from testing the accuracy of wearable devices, validating data processing algorithms, to innovating sensor material designs to improve signal performance and user comfort.

The study by Migueles et al. (2022) provides an important starting point, comparing four research accelerometer devices—Move4, ActiGraph GT3X+, GeneActiv, and Axivity. The results showed that, when raw data were processed using identical protocols, all four devices yielded very high levels of agreement in measuring activity and sleep behavior. However, small biases were also found in GeneActiv, especially in sleep and moderate-vigorous intensity activity (MVPA) parameters. These findings confirm that reliability depends not only on hardware but also on consistency in processing algorithms and the selection of analytical metrics.

Meanwhile, Lang et al. (2025) expanded the context of sensor validation by developing a machine learning-based biomechanical predictive model. By using an insole sensor integrated with the Temporal Convolutional Network (TCN) and Transformer algorithms, this study showed that the ground reaction force (GRF) in runners can be predicted in real-time outside the laboratory with a high level of accuracy. This proves that wearables are now able to measure not only basic activities, but also complex biomechanics, as long as the algorithm and sensor work synergistically.

Support for comfort and signal quality was also highlighted by Liu et al. (2020), who evaluated flexible sensors made of graphene and elastic metal. This study confirmed that these advanced materials are able to improve the signal-to-noise ratio, electrocardiography (ECG) accuracy, and respiratory rate monitoring, without sacrificing wearer comfort. This innovation is very important, especially for long-term use in clinical and non-clinical users.

Gomaz et al.'s (2023) study adds a perspective from the world of sports. Using wearable sensors to capture pelvic and torso kinematics, the team developed a baseball pitch type classification using Random Forest and Naive Bayes algorithms. While the accuracy is not perfect, this study paves the way for the development of wearables as biomechanical data-based athletic performance analytics tools, rather than simply motion trackers.

Finally, Seshadri et al. (2024) presented evidence of wearables in longitudinal training monitoring of an NCAA Division III soccer team. The training load data collected allowed coaches to identify patterns of physical stress and adjust training intensity, resulting in a 21% reduction in injury incidence. Although not focused on technical sensor validation, this study demonstrated that the reliability of data from verified sensors can be operationalized in real-world decision making, even in competitive sport contexts.

Overall, the five studies show that the validity of wearables depends on a combination of hardware design, processing algorithms, material innovation, and representative field validation. With high reliability, wearables can transform from mere tracking devices into predictive platforms and data-driven decision-making, both in the world of health, sports, and the general public lifestyle.

Theme 5: Injury Prevention & Athlete Performance Optimization (4 studies)

The four studies in this theme demonstrate how wearable biosensors are increasingly playing a strategic role in supporting injury prevention and optimizing athletic performance. While the contexts and methods used vary, all articles demonstrate the relevance of using wearables as a tool to precisely measure physical load, detect biomechanical imbalances, and inform adaptive training decisions.

The study by Preatoni et al. (2022) provides a conceptual foundation by confirming that inertial sensor-based wearables have great potential in detecting asymmetric loading and early signs of fatigue, two factors that significantly increase the risk of musculoskeletal injuries. Although much of the research is still in its early stages and confined to the laboratory, this study highlights the direction of wearable development for dynamic motion monitoring in the field.

In line with this, Seshadri et al. (2024) provided longitudinal evidence based on real-world practice in an NCAA Division III football team. By monitoring daily training loads over a full season, coaches were able to personalize training intensity for each player. As a result, the incidence of injuries was reduced by 21%. This shows how reliable wearable data can be directly translated into practical interventions in athlete performance and health management.

A more technical approach was demonstrated by Lang et al. (2025), who used insole sensors combined with machine learning models (TCN and Transformer) to predict ground reaction force (GRF) and tibial bone force (TBF) in real-time while runners were training. This is particularly important given that bone stress injuries often occur without obvious initial symptoms. By moving biomechanical analysis systems from the laboratory to the field, this study opens up a great opportunity for portable and continuous injury risk monitoring.

The fourth study, from Gomaz et al. (2023), integrated wearables with a classification algorithm to identify pitch types (fastball, curveball, etc.) in baseball athletes through analysis of trunk and pelvis kinematics. While the classification accuracy still needs to be improved, this approach highlights the potential of wearables for sport-specific technique analysis, which could be used to improve performance while preventing injury-prone movements.

The connection between the four studies lies in the systematic effort to make wearables a predictive and adaptive tool in athlete management, not just a tracking tool. From a preventive perspective, wearables support the detection of movement patterns that have the potential to cause injury. From a performative perspective, wearables allow coaches and athletes to manage training intensity based on personal data, which not only maintains fitness but also accelerates recovery and physiological adaptation.

Integrally, this theme asserts that wearable biosensors, when supported by intelligent algorithms and contextual validation, can revolutionize traditional approaches to athlete training and protection. The synergy between biomechanical data, predictive analytics, and on-field applications paves the way for a more precise, efficient, and long-term sports science oriented towards athlete health.

Theme 6: Implementation, Ethics & Clinical Integration (6 studies)

This theme summarizes a very crucial aspect of the use of wearable biosensors, namely, how this technology can be implemented effectively, ethically, and integrated into the health system. The six studies analyzed provide a comprehensive picture from various perspectives, ranging from technical readiness, privacy regulations, to psychosocial impacts that complement each other in explaining the complexity of wearable adoption in real practice.

The study by Smuck et al. (2021) provides a strong conceptual basis. They emphasize that the successful implementation of wearable technology in the healthcare sector depends on four main pillars: data accuracy, clinical relevance, user compliance, and integration into electronic health record (EHR) systems. Without these four components, wearables will struggle to become part of a sustainable healthcare ecosystem.

In line with that, Öztürk & Azizoğlu (2025) highlighted the application of wearables in nursing practice, especially in elderly monitoring, fall prevention, and clinical decision support. However, this study also highlighted real barriers such as cost, the need for technical training, and doubts about data privacy security, which can be major barriers in the context of health care in developing countries.

Meanwhile, Becking-Verhaar (2023) showed empirical results of the implementation of wireless sensors for vital sign monitoring in general wards. Although these devices have been shown to accelerate the detection of deteriorating patients, practical issues such as installation complexity and disruption to nurses' workflow are major challenges that need to be addressed through a more user-centered design approach.

From the perspective of technological development, Liu et al. (2020) emphasized that improving the comfort and accuracy of wearables through flexible sensors made of graphene and elastic metals is an important solution so that wearable devices can be applied in the long term without causing physical or psychological burdens for users. This material innovation directly supports the acceptance and adoption of technology in the clinical world.

The ethical and social dimensions are sharply highlighted by Ali & Iqbal (2025) through the concept of technoference, namely the disruption of family relationships and emotional well-being of adolescents due to excessive use of digital technology. This study warns that although wearables are intended to improve health, uncontrolled or non-contextual use can have a negative impact on quality of life and social interactions.

Finally, Duncker et al. (2021) extend the context to the cardiovascular system, showing that wearables are already widely used for monitoring arrhythmias, heart failure, and sleep apnea. However, a major challenge they highlight is the need for rigorous clinical validation and thorough integration into formal diagnostic protocols. This suggests that while wearables are technologically promising, their acceptance in the formal medical realm still requires strong cross-sectoral work.

From the six studies, it can be concluded that the implementation of wearables is not enough to only focus on its technological capabilities, but must also consider the health system infrastructure, the readiness of medical personnel, privacy regulations, user digital literacy, and psychosocial impacts. The interconnectedness of these studies illustrates that the adoption of wearables in clinical and community contexts requires a multidisciplinary approach that combines technical, human, and policy aspects.

Thus, wearable biosensors will be able to transform into truly effective digital health tools only if implemented through an integrative model—connecting technological innovation, responsive clinical practice, and an ethical framework that is protective of individuals and society.

Discussion

High compliance despite low individual motivation underscores the importance of external scaffolding, such as integrating devices into campus health programs or curricula. Behavioral science applications need to focus on environmental nudges and ease of use, not just increasing intrinsic motivation. (Wu et et al., 2024). Concrete target-based interventions (10,000 steps) are more effective than simply monitoring, but the effects decline without maintenance boosters. Gamification and just - in - time adaptive interventions may maintain long-term effects. Inconsistency in the screen-time relationship with sedentary behavior indicates the need to separate application types when designing intervention messages. HRV, heart rate, and multi-sensor vitals are predictive of cardiometabolic risk even in young healthy populations. Clinical validation shows that ultra-short measurement sessions (≤ 2 minutes) are sufficient, opening up opportunities for real-time coaching. In hospital care, wireless sensors improve patient safety, but user-centred design for nurse workflow is essential for sustainable adoption.

Convergence of processing algorithms is crucial; the differences lie not in hardware alone but in the analysis pipeline. Machine - learning algorithms (TCN - Transformer, Random Forest) are expanding the capabilities of biomechanical prediction, but explainability must be maintained to be acceptable to medical practitioners. Wearables enable micro-periodisation: adjustment of daily training load based on biomarkers (e.g., HRV, accelerometry). Early evidence in DIII soccer suggests reduced injuries; similar studies in elite Asian leagues are scarce and represent a strategic research gap, especially in sports with high training schedules. Successful implementation intersects with data privacy regulations (GDPR, HIPAA) and interoperability with EHR. Cost-effectiveness has not been frequently analyzed; future studies need to include economic analysis to drive hospital adoption decisions. Technoference demands an ethical framework that balances health benefits with socio-psychological impacts on adolescents.

Conclusion

The results of this scoping review indicate that wearable biosensors have great potential in detecting and preventing sedentary lifestyles in adolescents and young adults. Through six main themes of user compliance, impact on physical activity, vital sign monitoring, sensor validity, athletic performance optimization, and implementation challenges, it is illustrated that wearable devices not only function as tracking devices but also as behavioral intervention media, early clinical detection support, and physical exercise optimizers. Although the level of short-term compliance is quite high, behavioral changes will not last without adaptive interventions and environmental support. The development of technologies such as machine learning and flexible sensors promises increased accuracy and comfort, but challenges in real-world implementation, such as ethical issues, system integration, and digital literacy, need special attention. Further research needs to focus on long-term effectiveness tests, cost-effectiveness studies, and implementation in local contexts such as schools and primary care in Indonesia. With the support of appropriate policies, user-centered design, and strong clinical validation, wearable health technology can be an important part of disease prevention and health promotion strategies in the digital era.

The practical implications of this scoping review can provide a study to recommend in Education & Campus, namely, including wearables in sports courses/KKM to nudge active lifestyles. While in Health Services, to make recommendations for prioritizing clinically certified sensors and “plug and play” data integration into EHR. And in the Industrial sector, recommendations focus on material comfort and battery life while providing an open Software Development Kit for research

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