Review Paper

Scoping Review of Wearables in Monitoring Opioid, Tobacco, and Alcohol Abuse: A Potential Intervention for West Virginia

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Abstract: Wearable technology is a useful tool to tackle the problem of substance abuse among populations by tracking and monitoring addictions and offering diagnosis by proxy. This review seeks to understand the role of wearable technology in managing addiction, with particular focus on opioid, alcohol, and tobacco abuse. We adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines and conducted a comprehensive search of PubMed, PubMed Central, Web of Science (WoS), and IEEE Explore databases. English-language peer-reviewed articles published between 2013 and 2022 that examined the use of wearable devices for addiction management were included. The review acknowledged 25 relevant studies from various countries, primarily the United States. A majority of the studies examined alcohol addiction, with Secure Continuous Remote Alcohol Monitor (SCRAM) being the most commonly used technology. Our findings highlight the positive impact of wearables such as Q sensor™ Affectiva, Spire Health Tag, and Empatica E4 sensors on monitoring and managing opioid addiction, including their potential in addressing the opioid crisis in the United States. Moreover, the data underscored the importance of wearable technology in studying smoking patterns, with devices like (Automated Smoking Perception and Recording) ASPIRE and (Personal Automatic Cigarette Tracker) PACT 2.0 showing high agreement with other indicators of smoking characteristics. Despite the progress made, the review identifies a need for more research into wearables for opioid addiction.

Keywords: Wearables; healthcare; monitoring; drug abuse; addiction; alcohol; tobacco; opioid.

Introduction

The World Health Organization describes drug and alcohol addiction as the repeated use of psychoactive substances, resulting in the user becoming occasionally and persistently intoxicated, exhibiting a strong drive to engage in substance intake, having no control over reducing or discontinuing substance use, and making an effort to obtain psychoactive substances regardless of the means (Roberts et al., 2013; Yasar, 2022, May). The phenomenon of drug use in the United States presents a complex challenge, characterized by its multifaceted impact on individual health, societal well-being, and economic burden. The federal budget allocated for drug control in 2020, amounting to $35 billion, reflects the substantial financial resources directed towards addressing drug abuse in the United States. However, this budget does not encompass the entirety of the economic impact of drug abuse. The economic burden of prescription opioid overdose, abuse, and dependence in the United States has been estimated to be significant, with approximately one quarter of the cost borne by the public sector in health care, substance abuse treatment, and criminal justice costs (Florence et al., 2016). Furthermore, the societal costs of prescription opioid abuse, dependence, and misuse in the United States have been reported to impose a large economic burden on the workplace, the justice system, and society as a whole (Birnbaum et al., 2011).

According to data from the National Center for Drug Abuse Statistics, an estimated 138.54 million Americans have engaged in illicit drug use at some stage in their lives (Scholl et al., 2018). In a concerning trend, there were 106,699 drug overdose deaths in the United States in 2021, marking a 14% increase from the previous year. This surge in fatalities is a reflection of the escalating public health crisis. In analyzing the types of substances involved, heroin-related overdoses have shown a decline, with a nearly 32% decrease in death rates from 2020 to 2021 (*Drug Overdose Deaths*, 2021).

Conversely, synthetic opioids, particularly those other than methadone, have exhibited a troubling rise in overdose deaths (Jones et al., 2018; Madras, 2018). The death rate involving synthetic opioids increased by over 22% from 2020 to 2021, accounting for nearly 88% of all opioid-involved deaths (*Drug Overdose Deaths*, 2021). Critical to this rise is the prevalence of illicitly manufactured fentanyl, not linked to prescription rates but rather to illegal production and distribution networks (O'Donnell et al., 2017). Fentanyl, a synthetic opioid significantly more potent than heroin and morphine, is increasingly being found as a contaminant in other illicit drugs such as heroin, cocaine, and methamphetamine (Grover et al., 2023). In a comprehensive 10-state study, more than half of the opioid overdose deaths involved fentanyl (O'Donnell et al., 2018).

Beyond the realm of illegal substances and prescription drugs, the use of legal substances such as alcohol. According to the 2020 National Survey of Drug Use and Health (NSDUH), approximately 138.52 million Americans aged 12 and older consume alcohol, with a worrying 20.4% of them struggling with an alcohol use disorder (AUD) (O'Donnell et al., 2020). The prevalence of alcohol consumption is underscored by the statistic that most American adults have consumed alcohol at least once in their lifetime, and 6.7% of them develop AUD. Notably, younger demographics are increasingly represented in alcohol-related fatalities, highlighting a shift in the patterns of alcohol abuse (O'Donnell et al., 2020). Alcohol causes 10% of deaths among 15- to 49-year-olds and contributes to 5.3%-6.0% of the world's deaths (*Alcohol Abuse Statistics*, 2020). Men are three times as likely as women to die from alcohol abuse, and excessive alcohol use is responsible for 7.1% of diseases among males and 2.2% among females (*Alcohol Abuse Statistics*, 2020).

In addition to alcohol, tobacco and nicotine product use remains pervasive. In 2019, an estimated 50.6 million U.S. adults (20.8%) reported currently using any tobacco product, including cigarettes (14.0%), e-cigarettes (4.5%), cigars (3.6%), smokeless tobacco (2.4%), and pipes (1.0%) (Cornelius et al., 2020). Moreover, the use of tobacco products among middle and high school students has been a concern, with approximately one in four high school students and one in five middle school students reporting cravings for tobacco products (Wang et al., 2019). The 2021 National Youth Tobacco Survey indicates that even middle school and high school students have used nicotine pouches (Speciale et al., 2023).

This overview underscores the urgency and complexity of the drug overdose crisis in the United States. The increasing prevalence of synthetic opioids, particularly fentanyl and its analogs, is a central factor in the rising tide of drug-related fatalities. This situation calls for enhanced public health strategies, focusing on awareness, prevention, and targeted interventions to address this critical issue. Recently, wearable technologies have shown their potential to address drug and alcohol abuse (Carreiro et al., 2020; Goldfine et al., 2020; Mahmud et al., 2019), particularly alcohol, tobacco, and opioid addiction (Hriatpuii et al., 2022). Wearables are mobile electronic devices an individual unobtrusively wears as a medical accessory, typically for remote monitoring of physiological activities (Lukowicz et al., 2004; Oesterle et al., 2022). Given the implications of opioid, tobacco, and alcohol abuse and the emerging potential of wearable technologies as a method for intervention, there is a pressing need to conduct a comprehensive literature review. Our scoping review aims to understand the usage of wearables in reducing, managing, or detecting substance use disorder. By investigating the potential applications of wearables in this context, the review aims to identify innovative strategies and technological interventions that could augment current approaches to substance abuse treatment and prevention.

Materials and Methods

This literature review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines (**See S1 Checklist**). The review relied on PubMed, PubMed Central, Web of Science (WoS), and IEEE databases, with the assistance of professional librarians, to procure peer-reviewed articles meeting this study's scope and eligibility criteria.

Search terms were meticulously selected to encapsulate relevant literature in the field of wearable technologies applied to addiction and substance abuse management. Keywords such as "wearables," "addiction," "drug abuse," "substance abuse," "healthcare," and "health monitoring" were utilized, and their combinations were systematically applied across the three chosen databases to maximize the yield of pertinent articles.

The search was confined to articles published in English from January 1, 2013, to December 2022. The focus was on peer-reviewed publications that discussed the employment of wearables in reducing, managing, or detecting alcohol, opioid, or tobacco addiction. Studies with insufficient clarity regarding the type of wearable employed or the specific addiction targeted were systematically excluded from the final analysis.

Two independent researchers undertook the selection and eligibility assessment of the retrieved publications—initial screening involved examining titles and abstracts and eliminating duplicate articles. The full texts of the remaining articles were then thoroughly reviewed to conclude the selection process. In the event of any discrepancies or disagreements between the researchers, these were resolved through discussion and, when necessary, consultation with the senior author to reach a consensus. To ensure the comprehensiveness of our systematic review, we employed the snowballing technique alongside our primary search results. This method was crucial in guaranteeing that no relevant articles were inadvertently omitted from our analysis. Snowballing involves two key approaches: backward and forward snowballing. Backward snowballing entailed scrutinizing the reference lists of the studies initially identified, allowing us to uncover earlier works that contributed to the field but may not have been captured through database searches. Forward snowballing, on the other hand, involved identifying and examining later studies that cited our initially identified sources, thereby capturing more recent research developments.

Study quality was independently rated by two investigators using quality assessment tools specific to the design of the study in question (available at: https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools). A standardized data abstraction form was implemented to extract and systematically report pertinent information from each publication, including the authors, study objectives, methods, and results. For efficient analysis, each article was classified using this form based on the reported type of wearable technology and the specific substance abuse or addiction addressed. This methodical approach ensured a coherent and consistent review process, aiding the synthesis of findings from a diverse range of literature.

Results

Fig 1 illustrates the flowchart of the selection process of the articles included in this systematic literature review. The initial search using a set of queries displayed a total result of 5762 publications of which 2988 publications were PubMed Central, and 228 publications were IEEE, 1048 WoS and 1498 PubMed. We identified 19 articles from snowballing method.

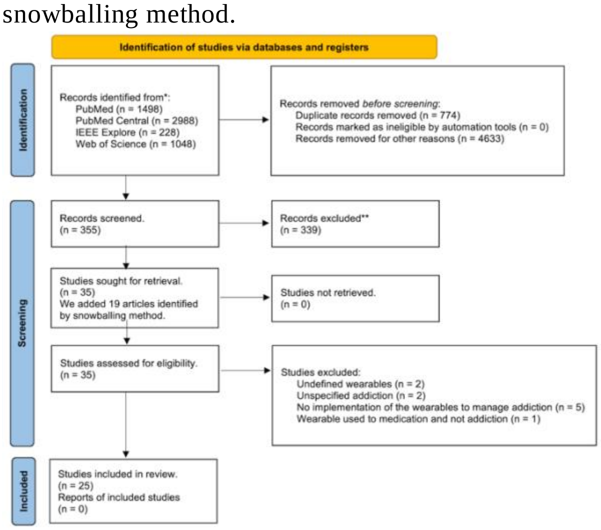

Figure 1. PRISMA-ScR. The process of selecting eligible publications for inclusion was used in this scoping review.

Firstly, we removed the duplicates (n= 774), all reviews/opinion/ perspective papers (n=324), short abstracts (n=502), and irrelevant articles that either focused on technology development, medical treatment, and did not focus on opioid, alcohol, or tobacco use (n=3807). The two authors independently reviewed 355 articles and shortlisted 35 eligible studies after screening their abstract. After reviewing the full text of these articles, 10 articles were removed that failed to satisfy our inclusion criteria. The final number of studies included in the systematic review was 25, with the consensus from all the authors.

Table 1 provides the summary of various research studies that utilize wearable technology in substance addiction research. The "Reference" column provides the citation for each study. The "Objectives" column outlines the primary purpose or goals of each individual study. The geographical location where each study was conducted is indicated in the "Country of Study" column. The "Wearable Used" column specifies the wearable device that was utilized for data collection in each research study. The type of substance addiction investigated in the research (such as alcohol, opioids, or tobacco) is represented in the "Addiction Type" column. Lastly, the "Findings" column presents the key results or conclusions drawn from each study.

Wearables for opioid monitoring

Five studies, all conducted in the United States, investigated the use of wearable biosensors for detecting and predicting opioid use with promising results. (Carreiro et al., 2016) demonstrated that the Q sensor™ Affectiva detected physical changes post opioid administration, indicating potential for real-time relapse detection. (Roth et al., 2021) suggested the Spire Health Tag could serve as a passive surveillance device detecting physiological responses to opioid use, which could prove instrumental in preventing overdose. (García et al., 2022) found that machine learning algorithms could accurately predict opioid use when used with Empatica E4 sensors, showing considerable potential for wearable technology in addiction treatment and prevention. Another study by (Carreiro et al., 2015) supported these findings, revealing that Q sensor™ Affectiva effectively detected real-time drug use. Finally, (Chintha et al., 2018) identified significant physiological changes detected by the E4 wrist-mounted biosensor as the opioid antagonist naloxone wears off, potentially informing the timing of clinical interventions. (Carreiro et al., 2020) also conducted a study in the United States examining the effectiveness of wearable sensor technology in the context of substance use disorders, specifically targeting opioids and tobacco. The team employed the Empatica E4 wearable sensor - a non-invasive wrist-mounted device - to detect and differentiate between self-reported episodes of craving and stress. The study found that participants responded positively to the wearable sensor. Furthermore, it was found to contribute to increased mindfulness and feelings of connectedness during the recovery process, highlighting its potential usefulness as a supportive tool in addiction treatment.

Wearables for alcohol monitoring

We identified 12 studies from around the world examining the utility of wearable biosensors for the detection and management of alcohol use.

In Israel, (Nassi et al., 2022) introduced the "Virtual Breathalyzer," which uses motion sensors in smartphones and wrist-worn devices. This innovative method showed potential as an alternative to traditional blood and breath tests for intoxication detection. In Scotland, (Neville et al., 2013) examined the impact of continuous transdermal alcohol monitoring on alcohol consumption among male university students. They found that participants significantly reduced their alcohol intake when asked not to consume alcohol while wearing the Secure continuous remote alcohol monitor (SCRAM).

In the United States, a series of studies further explored the capabilities of wearable biosensors. (Mun et al., 2021) assessed the correlation between Transdermal Alcohol Content (TAC) readings and self-reported alcohol use among homeless adults with alcohol misuse. They reported a moderate concordance between Ecological Momentary Assessment (EMA) and SCRAM, but a weak concordance between Timeline Follow Back (TLFB) with EMA or SCRAM. (Barnett et al., 2017) evaluated a Contingency Management intervention for alcohol use reduction using SCRAM data. The outcomes were positive, with the contingent reinforcement group showing fewer drinking days and lower TAC levels compared to the non-contingent reinforcement group. Further investigations by (Alessi et al., 2019) characterized drinking behaviors in alcohol use disorder patients under usual care. Their findings highlighted the higher prevalence of alcohol use detected by biosensors compared to self-reports. (Russell et al., 2022) demonstrated the indicative role of TAC features in drinking intensity and alcohol-related consequences, independently corroborating self-reported drinking data. (Fairbairn & Kang, 2019) compared the Skyn prototype with SCRAM for TAC detection, noting quicker detection times with the Skyn despite a higher failure rate.

(Rash et al., 2019) conducted a feasibility and acceptability assessment of alcohol monitoring among heavy-drinking soup kitchen attendees, involving daily breath samples and continuous transdermal monitoring. The study did not find significant differences in demographic or alcohol-related variables. (Richards et al., 2021) focused on the association of socio-demographic and clinical factors with TAC, finding significant associations with aspartate transaminase (AST) levels and the number of self-reported drinks.

The feasibility, acceptability, and adherence of the SCRAM device were evaluated in clinical research trials by (Alessi et al., 2017). Feedback from these trials suggested improvements in its size, weight, and noise level. (Barnett et al., 2014) established the SCRAM sensor's ability to detect varying levels of self-reported alcohol consumption. Lastly, (Dougherty et al., 2014) assessed the effectiveness of transdermal alcohol monitors in implementing contingency management treatment for non-treatment seeking drinkers, finding them effective in reducing heavy drinking patterns.

Wearables for tobacco monitoring

We identified 7 studies exploring wearable biosensors in the context of tobacco addiction. The studies underscore the significant advancements in wearable technology for tobacco addiction, primarily focusing on diagnosing and monitoring smoking patterns. In the United States, (Cole et al., 2021) validated the Automated Smoking Perception and Recording (ASPIRE) smartwatch (Polar M600) for studying smoking patterns in a controlled setting, revealing high agreement with established indicators of smoking characteristics. This suggests its efficacy in diagnosing smoking behavior. Concurrently, (Belsare et al., 2022) assessed how a topography mouthpiece device (PACT 2.0) influences smoking behavior, observing significant differences in various smoking metrics under different conditions, contributing primarily to the diagnosis and characterization of smoking habits.

In Indonesia, the study by (Sumartiningsih et al., 2019) employed a pulse oximeter and automatic sphygmomanometer to examine the physiological effects of smoking, such as heart rate recovery (HRR) and heart rate variability (HRV). This research provides diagnostic insights into the acute physiological impacts of tobacco consumption. In the Netherlands, (Shoaib et al., 2016) improved the detection of smoking events using a multi-layer algorithm in smartwatches (LG Watch R, LG Watch Urbane, Sony Watch 3), enhancing the diagnostic precision.

In the United States, (Senyurek et al., 2019) utilized a wearable sensor system (PACT 2.0) combined with an electronic lighter to accurately detect smoking events, suggesting a potential role in both diagnosis and management of smoking behavior. Similarly, (Imtiaz et al., 2017) demonstrated the effectiveness of the PACT 2.0 system in monitoring cigarette smoking in real-life conditions, reinforcing its diagnostic capabilities.

In the United Kingdom, (Skinner et al., 2019) validated the Stopwatch system using an LG model smartwatch in laboratory and real-world environments. The system's data showed substantial agreement with traditional paper diaries, indicating its potential for accurate smoking behavior monitoring.

Table 1. Evidentiary table of selected 25 publications.

Study	Objective	Country of study	Wearable	Addiction	Particip ant (n)	Findings
(Carreiro et al., 2016)	Detection improvement of relapse via real-time physiologic data on opioid use for clinicians' use in behavioral interventions.	United States	**Q sensor™ (Affectiva)** This is a wearable wireless biosensor that measures emotional arousal (excitement, anxiety, and calm) via skin conductance, as well as temperature and movement. It's designed to be worn on the wrist.	Opioid	30	The research detected a consistent decrease in locomotion and an increase in skin temperature using wearable biosensors after opioid administration.
(Roth et al., 2021)	Feasibility assessment of a wearable biosensor to capture physiological	United States	**Spire Health Tag** These are small devices that adhere discreetly to clothing	Opioid	16	The study likely presents evidence of the effectiveness of wearable biosensors in capturing physiological indicators such as

	changes related to opioid overdose in a real-world setting.		(like a bra or underwear) and record respiration, sleep, heart rate, and daily activity data. This data syncs with the Spire Health Tag App and can be sent to a healthcare provider.			changes in heart rate, respiratory rate, and other relevant parameters that are indicative of opioid overdose.
(García et al., 2022)	Validation of wearable sensor technology for detecting self-administration of prescription opioids using machine learning.	United States	**Empatica E4 sensors** It is a wristband with four sensors: a photoplethysmography sensor, an electrodermal activity sensor, a 3-axis accelerometer, and an optical thermometer. These sensors are used to collect continuous and instantaneous physiological data such as temperature, movement, EDA, and heart rate	Opioid	46	The study demonstrates the potential of wearable devices in accurately identifying opioid self-administration through machine learning algorithms. The algorithms predicted opioid use accurately, particularly 14-21 minutes after administration.
(Carreiro et al., 2015)	Utility assessment of a device to detect opioid use by measuring physiologic change after known exposure.	United States	Q sensor™ (Affectiva, Waltham, MA)	Opioid	5	The study focused on four emergency department patients receiving parenteral opioids and one individual using cocaine. The biosensors monitored parameters such as skin temperature and galvanic skin response to detect substance use. Mobile biosensors effectively detected drug use in real time.
(Chintha et al., 2018)	Identification of the physiologic change that marks the cessation of naloxone's effect.	United States	E4 wrist-mounted biosensor	Opioid	20	The study revealed that physiologic changes consistent with the onset of opioid drug effect were observed across various parameters. Statistical significance was only found in changes related to heart rate and skin temperature. This suggests that wearable biosensors, in conjunction with the Hilbert transform approach, can effectively monitor and evaluate physiological responses following naloxone administration in cases of recurrent opioid toxicity.
(Carreiro et al., 2020)	Accuracy assessment of a wearable sensor to detect and differentiate episodes of self-reported craving and stress in individuals with substance use disorders.	United States	Empatica E4 wearable sensor non-invasive wrist-mounted sensor.	Opioid and Tobacco	30	The data collected from the wearable sensors provided valuable insights into the fluctuations in heart rate that corresponded to periods of heightened stress and increased craving for substances.
(Nassi et al., 2022)	Presentation of a new intoxication detection method, Virtual Breathalyzer, utilizing motion sensors of smartphones and wrist-worn devices.	Israel	Microsoft Band and Samsung Galaxy S4 (Drager Alcotest 5510 breathalyzer)	Alcohol	30	The study found that it is feasible to detect intoxication using motion sensors in commercial wearable devices. By analyzing the data obtained from these sensors, the researchers were able to identify patterns and indicators associated with intoxication, demonstrating the potential for using consumer-grade devices for this purpose. The results indicated an area under the curve (AUC) of 0.97 and a false positive rate (FPR) of 0.04, given a fixed true positive rate (TPR) of 1.0. These findings demonstrate the robustness and reliability of the Virtual Breathalyzer approach in accurately identifying intoxication levels using motion sensors in commercial wearable devices.
(Neville et al., 2013)	Examination of the impact of continuous transdermal alcohol monitoring on alcohol consumption in male students at a Scottish university.	Scotland	**SCRAM** This is an ankle bracelet that monitors alcohol content in sweat.	Alcohol	60	Participants asked not to consume alcohol while wearing a continuous alcohol monitor drank significantly less.
(Mun et al., 2021)	Assessment of correlation between TAC readings and self-reported alcohol use in adults with alcohol misuse who are homeless.	United States	SCRAM	Alcohol	49	The study found weak concordance between the Timeline Follow-Back (TLFB) method and either Ecological Momentary Assessment (EMA) or Secure Continuous Remote Alcohol Monitoring (SCRAM) among adults experiencing homelessness. This study is the first to examine the concordance of alcohol use estimates using EMA, SCRAM, and TLFB methods in this population.

(Barnett et al., 2017)	Evaluation of a CM intervention for reducing alcohol use, using alcohol sensor data from the SCRAM bracelet.	United States	SCRAM	Alcohol	30	The study indicate that contingency management (CM) led to a higher percentage of days with no drinking detected compared to the non-contingent group during the intervention weeks. Specifically, the study found that the contingent reinforcement (CR) group had a significantly higher percentage of days with no drinking detected (54.3%) compared to the non-reinforcement (NR) group (31.2%) during the intervention weeks ($p = .05$, Cohen's $d = 0.74$; 95% CI: 007–1.47).
(Alessi et al., 2019)	Characterization of drinking behavior using SCRAM in alcohol use disorder patients under usual care treatment.	United States	SCRAM	Alcohol	63	High prevalence of alcohol use in outpatient care was detected by biosensors, not by self-reports.
(Russell et al., 2022)	Demonstration of the indicative role of TAC features in drinking intensity and alcohol-related consequences, independent of self-reported drinking.	United States	SCRAM	Alcohol	222	The study demonstrates the utility of transdermal alcohol concentration (TAC) sensors in studying alcohol misuse among young adults in natural settings. The study reveals that TAC sensor features correlate with ecological momentary assessment (EMA) drinking reports and can predict alcohol-related consequences at the day-level. The authors found that TAC features added predictive value to the day-level prediction of alcohol-related consequences, supporting the use of TAC sensors in understanding alcohol consumption patterns and related outcomes in natural settings.
(Fairbairn & Kang, 2019)	Examination and quantification of lag times between ingested alcohol and TAC via a range of metrics.	United States	SCRAM and Skyn	Alcohol	30	The study compared the TAC measured by the biosensor with TAC measured by SCRAM under controlled laboratory conditions. The results indicated that the TAC measured by the wrist-worn biosensor peaked over an hour earlier than the TAC measured by SCRAM, with statistically significant differences. Additionally, the time-series models suggested that the wrist-worn biosensor TAC lagged behind breath alcohol concentration (BrAC) by 24 minutes, while SCRAM TAC lagged behind BrAC by 69 minutes, further demonstrating the validity and favorable properties of the new-generation wrist-worn biosensor for transdermal alcohol detection
(Rash et al., 2019)	Feasibility and acceptability assessment of alcohol monitoring involving daily breath samples and continuous transdermal monitoring among heavy-drinking soup kitchen attendees.	United States	SCRAM	Alcohol	19	No group differences were found in demographic characteristics, homelessness history, soup kitchen use, or alcohol-related variables among adults with alcohol misuse.
(Richards et al., 2021)	Determination of the association of socio-demographic and clinical factors with TAC while controlling for the level of alcohol use.	United States	SCRAM	Alcohol	43	HIV status had no significant impact on peak TAC or daily TAC-AUC. AST and self-reported number of drinks significantly associated with peak TAC, while sex and self-reported drinks significantly affected daily TAC-AUC.
(Alessi et al., 2017)	Feasibility, acceptability, and adherence assessment of technology in two clinical research trials.	United States	SCRAM	Alcohol	100	SCRAM was found feasible, acceptable, and adherent in randomized clinical trials. Feedback suggested reducing its size/weight/noise level.
(Barnett et al., 2014)	Establishment of SCRAM alcohol sensor's ability to detect different self-reported alcohol consumption levels.	United States	SCRAM	Alcohol	66	Number of drinks consumed by participants was the primary determinant of detection of drinking episodes.
(Dougherty et al., 2014)	Assessment of the effectiveness of transdermal alcohol monitors for implementing contingency management in non-treatment seeking drinkers.	United States	SCRAM	Alcohol	26	Transdermal alcohol monitors were effective in implementing contingency management treatment to reduce heavy drinking patterns.
(Cole et al., 2021)	Testing the validity of a smartwatch for studying temporal patterns and	United States	ASPIRE on a Polar M600 smartwatch.	Tobacco	27	ASPIRE showed high agreement with other indicators of smoking characteristics,

	characteristics of smoking in a controlled lab setting.					surpassing CReSS in measuring puffs and IPIg.
(Belsare et al., 2022)	Assessment of how a topography mouthpiece device alters smoking behavior.	United States	PACT 2.0	Tobacco	45	Significant differences were observed in most metrics between two smoking conditions (with and without CReSS).
(Sumartingsih et al., 2019)	Examination of exercise induced HRR and HRV in subjects caused by inhaling smoke from TC and aerosolized vapor from ENDSs.	Indonesia	HR monitor (Pulse Oximeter, Elitecth) and Automatic sphygmomanometer (Omron Healthcare Co.)	Tobacco	24	Acute smoking increased HR and reduced DBP. No significant differences were found based on nicotine content.
(Shoaib et al., 2016)	Use of a two-layer hierarchical smoking detection algorithm for monitoring smoking.	Netherlands	LG Watch R, LG Watch Urbane, Sony Watch 3	Tobacco	11	Improved detection of smoking and eating/drinking was observed using a multi-layer algorithm.
(Senyurek et al., 2019)	Use of a wearable sensor system for accurate detection of smoking events.	United States	PACT 2.0	Tobacco	35	Combination of IMU and electronic lighter enhanced automatic monitoring of smoking.
(Imtiaz et al., 2017)	Development and validation of a multi-sensory wearable for monitoring cigarette smoking in free-living conditions.	United States	PACT 2.0	Tobacco	40	The PACT 2.0 system and instrumented lighter produced accurate responses in various circumstances.
(Skinner et al., 2019)	Implementation and preliminary validation of the Stopwatch system in laboratory and free-living conditions.	United Kingdom	LG model smart watch.	Tobacco	13	The smart watch system's data showed substantial agreement with paper diaries in free-living conditions.

SCRAM: Secure continuous remote alcohol monitor; TAC: Transdermal alcohol concentration; EMA: Ecological Momentary Assessment; ASPIRE: Automated Smoking Perception and Recording; CReSS: Clinical Research Support System; IPIs: Interpuff intervals; BrAC: Breath alcohol concentration; BAC: Blood Alcohol concentration; ALT: alanine aminotransferase; AUD: Alcohol Use Disorder; TAC-AUC: transdermal alcohol concentration - area under the curve; AST: aspartate transaminase; PACT: Personal Automatic Cigarette Tracker; EDA: Electrodermal activity; HRR: Heart rate response; HRV: Heart rate variability; TC: Tobacco cigarettes; ENDS: Electronic nicotine dispensing systems (ENDS); DBP: Diastolic blood pressure; SBP: Systolic blood pressure; IMU: Inertial Measurement Unit; HMG: Hand-to-mouth gestures; CM: Contingency Management

Limitations of studies

We also critically examined the limitations of studies reviewed in this study. The studies under consideration exhibit a range of methodological constraints, predominantly influenced by sample size, which bear significant implications for the interpretation and generalizability of their findings.

A recurrent limitation across studies such as those by (Carreiro et al., 2020; Carreiro et al., 2015; Carreiro et al., 2016) and (Fairbairn & Kang, 2019) is the constrained sample size, with participant numbers as low as 5 and seldom exceeding 30. This limitation critically impacts the generalizability of the results. Smaller sample sizes inherently limit the representativeness of the findings, as they may not adequately capture the diversity and variance present in larger populations. Moreover, small samples reduce statistical power, increasing the probability of Type II errors, where true effects may go undetected. Consequently, the findings from these studies should be interpreted with caution, particularly when considering their applicability to broader, more diverse populations.

Studies such as those by (Roth et al., 2021) and (García et al., 2022) demonstrate limitations related to the duration and specific settings of the research. The short-term nature of these studies may not capture the long-term patterns and effects, essential in understanding the dynamics of opioid and alcohol use. Additionally, the controlled or specific settings of these studies, such as healthcare facilities or demographic areas, limit the ecological validity of the findings, thereby constraining their applicability to real-world scenarios.

The studies by (Chintha et al., 2018) and (Cole et al., 2021) raise concerns regarding the reliability and validity of the measurement tools employed. Inconsistent or inaccurate data collection tools can significantly skew results, leading to erroneous conclusions. This is particularly pertinent in studies employing wearable sensors or self-report measures, where accuracy and consistency in data collection are paramount for valid interpretations.

Research by (Neville et al., 2013) and (Barnett et al., 2014) illustrates limitations in participant diversity. These studies often encompass a homogenous group, in terms of ethnicity, age, gender, or health status, which poses significant implications for the generalizability of the results. The lack of diversity in study samples restricts the applicability of the findings across different populations, potentially leading to biased or incomplete understandings of the phenomena under study. Further methodological limitations are noted in studies relying on self-report measures, which are subject to biases such as social desirability or recall bias, potential selection bias, and limitations in the technology or measurement techniques employed. Such factors can compromise the integrity and applicability of the research findings.

Discussion

This comprehensive review highlighted the growing potential of wearable technology as an effective tool in monitoring and predicting substance use across opioids, alcohol, and tobacco. It revealed that wearable devices, through the detection of physiological changes, can enhance real-time behavioral interventions and surveillance of opioid use. The devices also demonstrated remarkable utility in alcohol monitoring, showing promise as alternatives to traditional blood and breath tests, accurately reflecting drinking behavior, and effectively implementing treatment interventions to curb alcohol use. As for tobacco use, wearables proved beneficial in discerning temporal smoking patterns and distinguishing smoking activities from non-smoking ones, with an added advantage of enhancing mindfulness and connectedness in recovery. Despite the promising potential of wearables identified in this review, there is a noticeable absence of studies from lower-income countries. This indicates a gap in the research, suggesting a need for further exploration and potential implementation of wearable technology in these regions, especially given the global burden of substance misuse.

Over the past three decades, the United States has experienced an alarming surge in opioid overdose fatalities, a crisis which has grown particularly acute in recent years. According to the Centers for Disease Control and Prevention (CDC), opioid overdoses claimed 47,600 lives in the country in 2017, accounting for over two-thirds of all drug overdose deaths (Chintha et al., 2018). In this context, our review highlights the promising potential of wearable technologies as tools for combatting the opioid crisis.

Wearables for West Virginia

In West Virginia, a state grappling with one of the highest rates of opioid-related overdoses in the United States, the deployment of wearable technology harbors considerable potential. These advanced devices, capable of detecting physiological markers indicative of substance abuse, offer an innovative and proactive solution to the burgeoning crisis. They provide a mechanism for early intervention, facilitate continuous monitoring, and enable the development of personalized treatment modalities. This is particularly vital in addressing the complex challenges endemic to the state, such as limited access to healthcare in rural areas and the prevalent stigma surrounding substance misuse. The utility of these wearables extends beyond opioid misuse to encompass the monitoring of alcohol and tobacco use, thereby offering a holistic strategy in combating substance abuse.

Delving into the specifics, wearable devices like the Q sensor™ and Empatica E4 demonstrate the capacity for real-time physiological monitoring. This feature is crucial for the timely detection of substance use, thereby catalyzing immediate intervention strategies. Such an approach is acutely pertinent to the context of West Virginia, where opioid misuse is a significant concern. Integrating these wearables into structured behavioral interventions and contingency management programs could further bolster efforts to promote abstinence, offering tangible, objective evidence of an individual's compliance. Moreover, these technologies hold immense promise in aiding special populations, such as individuals experiencing homelessness, by providing them with focused and personalized support.

Enhancing the precision of self-reported substance use data is another critical benefit offered by these wearables, a factor essential for both efficacious treatment and robust research. The integration of wearable technologies with existing healthcare frameworks can lead to more comprehensive and continuous monitoring of individuals with substance use disorders. Such integration is pivotal for refining treatment plans and augmenting support mechanisms during both recovery and rehabilitation phases. However, the effective implementation of wearable technology in addressing substance abuse issues in West Virginia necessitates a tailored approach, one that judiciously considers local factors such as technology accessibility, privacy concerns, and the intricacies of the healthcare infrastructure.

To fully leverage the capabilities of wearable technologies in mitigating the substance abuse crisis in West Virginia, a strategic, multi-faceted approach is imperative. This strategy must encompass various dimensions, ranging from ensuring robust data security to seamlessly integrating these technological solutions within the existing healthcare paradigms (ecological validity). The thoughtful application of wearable technology, thus, stands as a beacon of hope in the state's ongoing battle against substance abuse.

Establishing stringent data privacy and security measures

One of the primary concerns with the use of wearable technology in healthcare is the protection of sensitive health data. In West Virginia, where the stigma associated with substance abuse could exacerbate privacy concerns, establishing stringent data privacy and security protocols is crucial. This involves developing robust encryption methods, secure data storage solutions, and clear policies regarding data access and sharing. Ensuring compliance with regulations such as HIPAA (Health Insurance Portability and Accountability Act) is essential. Additionally, educating users about how their data is used and protected can help build trust and encourage the adoption of these technologies.

Economic accessibility and Infrastructure Adaptation

The economic and infrastructural landscape of West Virginia poses significant challenges to the widespread adoption of wearable technologies. Ensuring that these devices are affordable is key to their accessibility. This might involve state-funded programs, subsidies, or partnerships with technology companies to lower costs. Moreover, given the rural nature of much of West Virginia, it is essential to ensure that these wearables are functional even in areas with limited technological infrastructure, such as poor internet connectivity. This could involve developing devices that can store data locally and sync when a connection is available or creating low-bandwidth solutions.

Designing user-friendly wearables

User adherence is critical for the effectiveness of wearable technologies in substance abuse monitoring. Designing user-friendly, non-intrusive devices that minimize stigma is essential. This involves considering factors like the physical design of the device, its comfort, and how discreetly it can be worn. User feedback should be a key component of the design process, ensuring that the wearables meet the needs and preferences of the individuals who will be using them. Reducing stigma can also be addressed through public awareness campaigns that normalize the use of such technology in healthcare and substance abuse treatment.

Conducting long-term studies

To validate the effectiveness of wearable technologies in substance abuse treatment, extensive and long-term studies are necessary. These studies should be tailored to the specific demographic and socio-economic contexts of West Virginia, ensuring that the findings are relevant and applicable to the state's population. Research should focus not only on the effectiveness of the technology in monitoring substance use but also on its impact on treatment outcomes, user experience, and overall healthcare costs. Collaborations with universities, research institutions, and healthcare providers can facilitate such comprehensive studies.

Integrating with traditional healthcare services

Finally, wearable technology should not be seen as a standalone solution but as part of a comprehensive approach to substance abuse treatment. This means integrating these devices with traditional healthcare services. Healthcare providers should be trained in using data from wearables to inform treatment plans. This integration also involves ensuring that the technology complements other treatment modalities, such as counseling, medication-assisted treatment, and support groups. Effective integration requires collaboration among technology developers, healthcare providers, policymakers, and patients.

Ensuring ecological validity

It is essential that these technologies are tested and proven effective in environments that closely resemble where they will be actually used. For West Virginia, this means considering rural settings, areas with limited internet access, and communities with varying socio-economic backgrounds.

The design and functionality of wearables should align with the specific challenges and lifestyles of the West Virginia population. This includes consideration of factors such as local cultural attitudes towards technology and substance abuse, the typical daily activities of users, and environmental factors that might affect the use of wearables, like weather conditions or the nature of predominant occupations.

Community participation

Engaging the community is key to the successful implementation of wearable technologies for substance abuse treatment. Community participation ensures that the deployment of these technologies is responsive to the needs and preferences of the people who will use them.

Educating the community about the purpose, benefits, and usage of the technology is essential for its acceptance. Transparent communication about data privacy, the goals of using the technology, and how it can aid in treatment can build trust and dispel fears or misconceptions.

Collaborating with local healthcare providers, academic institution, research centers, community leaders, and advocacy groups can facilitate the integration of the technology into the community. These stakeholders can play a vital role in advocating for the technology, providing feedback, and assisting in its distribution and adoption.

Establishing channels for ongoing feedback from users and community members can help in continuously improving the technology. This feedback can guide adjustments in the technology and its implementation strategy, ensuring that it remains relevant and effective.

Conclusion

In conclusion, the effective utilization of wearable technologies in combating substance abuse in West Virginia requires a multifaceted approach. This review, while thorough and comprehensive, does have a few limitations worth noting. First, it primarily focuses on studies conducted focusing on opioids, alcohol, and tobacco abuse, which may limit the generalizability of our findings. Second. our review might have overlooked relevant studies that were not indexed in the databases we searched, or those published in languages other than English. Third, the rapidly evolving nature of wearable technology presents a challenge, as newer models with enhanced capabilities might have emerged since the completion of the studies included in this review.

In conclusion, our systematic review elucidates the transformative potential of wearable technologies in combating substance misuse. This potential is especially relevant given the ongoing opioid crisis in the United States and the widespread prevalence of substance misuse worldwide. With the continuous evolution and increasing accessibility of wearable technologies, it becomes ever more vital to explore their capabilities in the realm of substance misuse, thereby maximizing their public health impact. We believe that these findings can serve as a catalyst for policy changes, new treatment approaches, and innovative research directions.

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