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Wearable Devices for Asthma Monitoring, Detection, and Management of All Ages: A Scoping Review

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Abstract: Asthma is a chronic lung disease, which might affect all ages and has its specific features of narrowing the airways. This kind of narrowing makes it difficult for asthma patients to breathe and therefore might trigger coughing, wheezing, chest tightness, and shortness of breath. Because of these features, asthma patients need to monitor, detect, and manage their asthma all the time, but it was hard to realize for them in the past. Luckily, nowadays, wearable devices have developed quite fast and rapidly, which might effectively fulfill the needs, thus reducing the terrible consequences caused by the sudden onset of asthma. Therefore, there is a need for a scoping review focusing on this topic. This scoping review was completed through 4 databases, including PubMed, IEEE Explore, Scopus, and Web of Science. It includes studies that have free full text and were published from 2010 to 2024, which mainly focused on the deep relation between the wearable devices' related sensors or platforms or remote systems and asthma so as to show the present developments and specific outcomes of asthma monitoring, detection, and management. The review eventually included a total of 19 papers filtered from 1081 papers. To sum up, this scoping review reveals that different studies have taken place through using various wearable devices to collect specific parameters, thus detecting, managing, and monitoring asthma patients. All these applications of sensors, platforms, and systems give asthma patients chances to better enjoy their lives.

Keywords: asthma, wearable devices, sensors

1. Introduction

Asthma is a common kind of chronic lung disease, which presently affects numerous people of all ages worldwide. Asthma patients suffer from asthma symptoms, such as wheezing, breathlessness, coughing, etc. Asthma significantly impacts the quality of daily life and can even pose a threat to their lifelong well-being. The disease exists because of a complex interplay of genetic and environmental factors, leading to an exaggerated airway response to various stimuli, including allergens, irritants, and respiratory infections. These results in airway inflammation, bronchospasm, and narrowing of the airways, hindering airflow, thus leading to the characteristic asthma symptoms.

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Asthma is the kind of disease that might accompany patients lifelong. Therefore, it can be quite dangerous when the sudden onset of asthma happens to patients. Moreover, this happens most commonly when the season changes, so it is definitely useful and necessary for patients to try to use wearable devices as the daily essential assistance.

Wearable devices have developed quite rapidly, combined with specific sensors, and been utilized in multiple platforms and systems, thus being used in our daily lives, which effectively help people to monitor specific diseases and prevent their potential risks, thus offering us opportunities to enjoy a more convenient and healthier life. These newly invented and developed sensors used in wearable devices and platforms and systems viewing wearable devices as their main parts help the relationship between wearable devices and asthma develop into a new stage these years, presently mainly related to the detection, monitoring, and management of asthma.

However, broad scoping reviews of wearable devices in asthma detection, monitoring, and management of all ages are lacking.

This scoping review will provide a basic review for the future studies to understand the links between the wearable devices and asthma. Therefore, make it easier for the future researchers to face the challenges and create more developments. I wish you the best of success.

2. Method Descriptions

This scoping review follows the PRISMA-ScR guide- lines, which in detail is called the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews. And this review was completed through 4 databases, including PubMed, IEEE, Scopus, and Web of Science, searching for free full-text studies that are published from 2010 to 2024, which mainly focused on the deep and close relation between the wearable devices, platforms, or remote systems and asthma so as to show the present developments and findings through different sensors, platforms, and systems.

2.1. Keywords and Databases

This scoping review searched related articles through PubMed, IEEE, Scopus, and Web of Science, 4 databases. The searching period lasts for 5 months from 26 May 2024 to 12 October 2024, and we use words and phrases related to:

(1) wearable: wearable, wearable devices, wearable sensors, wearable technology, wearable computer, remote control system, health control, and remote;

(2) the aim of using wearable devices: asthma detection, asthma monitoring, asthma management, and breathing and chest movement monitoring.

These words and phrases were selected to create search strings that can be generally used based on the Boolean AND and OR operators, as follows: (asthma) AND (“wearable” OR “wearable device*” OR “wearable sensor*” OR “wearable techno*” OR “wearable computer*” OR “remote control system” OR “health control” OR “remote”).

The search words and phrases were tailored to each of the four databases, adhering to their guidelines. As described and written in the following section, these words and phrases are used to apply filters so as to ensure that the retrieved documents totally meet the inclusion criteria, including the language that they use, publication dates, and the type of documents. Exclude those studies not written in English, without free full text, without all open access, and not published from 2010 to 2024.

DOI: 10.54254/2755-2721/108/2025.21195

Search query	Calalog	Results	Notes
(asthma)AND("wearable"OR "wearabledevice*"OR "wearable sensor*"OR"wearable techno*"OR "wearablecomputer*"OR "remote control system"OR "health control"OR "remote")	Pubmed	293	Article & All open access & 2010-2024
	IEEE Explore	6	
	Scopus	364	
	Web of Science	418	

Figure 1: An image of search results

2.2. Inclusion and Exclusion Criteria

The inclusion criteria are studies that are written in English and published as articles with open access and with free full text from 2010 to 2024.

In order to identify which articles to choose to discuss in this scoping review, health information technology us- ability study methodologies mentioned by Yen Bakken [1] are used. The framework written in this article outlines a vital evaluation approach for interactive health information technology usability study, including 5 distinct study types: (1) needs analysis to identify user requirements and inform initial system design; (2) lab sessions used to assess the performance of the system; (3) lab sessions used to evaluate the interaction between user and the system; (4) users' assessments of usability and quality aspects; and (5) users' feedback on the system's influence on health outcomes.

After synoptically describing the 5 distinct study types, our scoping review included studies of types 3, 4, and 5 in our scoping review. Therefore, we excluded studies that focus on unrelated topics, like COVID-19, medication adherence, and chronic diseases, and those existing scoping reviews, systematic reviews, and literature reviews.

2.3. Study Selection

This scoping review included a four-stage selection process: identification, screening through titles and abstracts, removing duplicates, and screening through details. (The details are illustrated in Figure 2).

As for the identification part, this initial stage involved a comprehensive search in four databases: PubMed, IEEE Explore, Scopus, and Web of Science for studies that are relevant to asthma. The result of this part is that 1081 studies are included.

As for the first screening part, titles and abstracts of the 1081 studies were reviewed to assess their suitability based on two main inclusion criteria:

1. Disease relevance: Did the study mention asthma?

2. Technology utilization: Did the study utilize a wear- able device, platforms, a remote system, or a specific sensor?

131 studies meet both criteria in the screening part.

As for the removing duplicate's part, 38 studies in 131 studies are removed because they are duplicates in the four databases. The rest of the 93 studies then entered into the second screening part.

As for the second screening part, full text is the ba- sic standard, which ends up excluding 4 studies from 93studies. The whole text and the details of the remaining 89 studies were later carefully reviewed to ensure they met the predetermined inclusion criteria.

11 studies are excluded because they are closely linked to COVID-19. 39 studies are excluded because they focus on conditions other than asthma. 12 studies are excluded because they are highly correlated with algorithms. 7 studies are excluded because they are highly relevant to the applications.

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1 study is excluded because it is imaging related. The above 70 studies are excluded mainly because they mention asthma in the studies, but just view asthma as an example.

Ultimately, 19 studies from 1081 studies, which only focus on asthma and the parameters collected by the multiple sensors, platforms, and systems, are included in this review. These studies were then further analyzed.

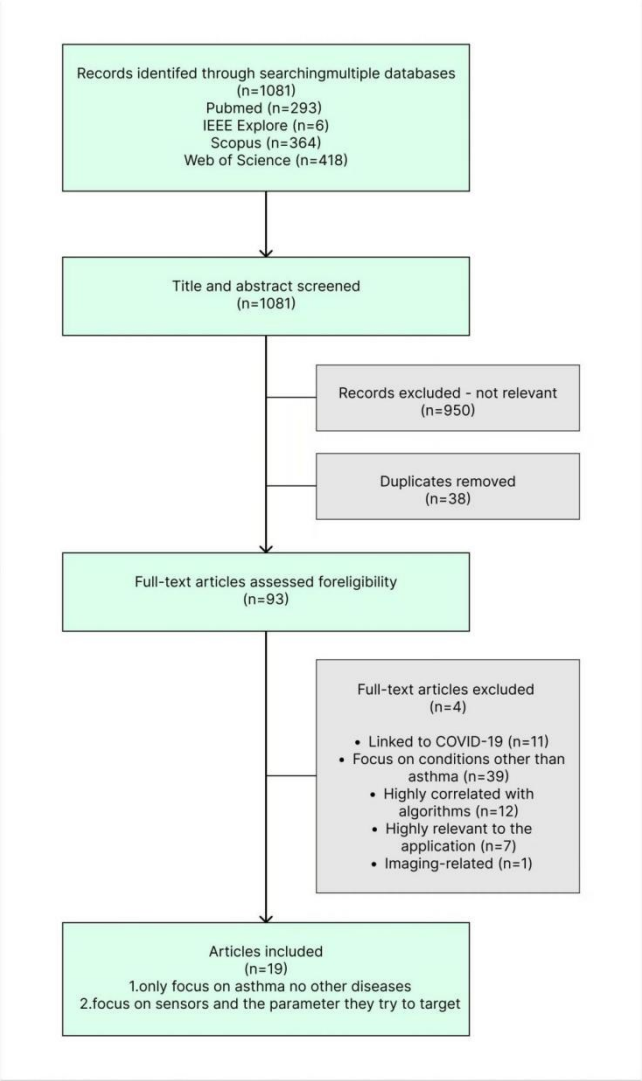

Figure 2: An image of the study selection process

Disagreements were all resolved through discussion and communication during the research period among the three authors. And the results were agreed upon and accepted by all three authors.

2.4. Induction and Analysis

Our scoping review mainly uses inductive measures to analyze data extracted from the 19 studies. Special platforms or specific systems or the sensors used in the wearable devices mentioned in the studies, combined with their corresponding measurement parameters, are summarized and classified in detail as follows. Their relations to asthma monitoring, detection, and management are also analyzed.

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As for the special platforms mentioned in the studies, they can be categorized as the nuvoAir platform [2], the digital self-management platform, Juli [3], and using the unique wearable platform to measure respiratory rate [4].

The nuvoAir platform has three parts: a smartphone application, a Bluetooth spirometer called AirNext, and the physician portal. The wearable device and vital core of this platform is a novel and ultra-portable device. [2] This platform monitored parameters that include peak expiratory flow, simplified to PEF; forced expiratory volume in one second, simplified to FEV1; and forced vital capacity, simplified to FCV, so as to reveal earlier subtle deterioration in lung function, thus making it possible for physicians to manage asthma as well as improving self-monitoring.

In the study of Juli, a self-management platform for asthma built on smartphones, they use an Asthma Control Test (ACT) as the basic standard to judge the platform's efficacy. [3] Through wearable devices, such as smart respiratory products, etc. Data can be collected to let the Juli put forward personal suggestions to asthma patients.

The platform mentioned in this study is the unique wearable platform combined with a VCSEL (non-invasive vertical-cavity surface-emitting laser) utilizing an adaptive signal processing method, which is realized through disassembling the signal processing optimizations into the bands of different respiratory rates. [4] Since respiratory rate as the parameter can be reflected by the signal produced by thoracic movement, the unique wearable platform, including an integrated photo-sensor, a microprocessor, and a disposable patch, plays the vital role of collecting these signals. This platform will help improve the level of asthma monitoring, detection, and management.

As for specific systems mentioned in the studies, they can be categorized as the portable respiration monitoring system [5], the wearable breathing sound monitoring system [6], the real-time monitoring system based on the Internet of Things (IoT) [7], and the low-power wearable system [8].

The key part of the pocket-sized respiration monitoring system is the capacitive sensor embroidered on the face mask and integrated with readout electronics so as to monitor interdigitated electrodes. [5] This sensor actually utilizes the feature of hygroscopic polyester thread, which is sensitive to humidity, as well as a capacitor, thus reflecting respiratory rate.

The wearable breathing sound monitoring system includes an acoustic sensor, which is located in the wireless breathing sound acquisition module, acquiring breathing sounds and transducing them into electrical signals. [6] The parameters are the breathing sounds, which are one of the indicator symptoms that reflect to what degree the airway is obstructed, thus showing the severity of asthma. Therefore, this system can help detect, monitor, and manage asthma patients.

The Internet of Things, simplified to IoT, is the basis of a real-time monitoring system that has multiple sensors, including the blood oxygen sensor-MAX30100 sensor that detects both the heart rate and the blood oxygen saturation (SpO_2) through detecting pulse and heart rate signals with the use of a photodetector and with the help of the low-noise signal processing function; the temperature sensor and the humidity sensor-DHT11 sensor that measures humidity and room temperature through a humidity sensor and a thermistor; the air quality sensor (the gas sensor)-MQ- 135 sensor that measures air quality; and the temperature sensor— LM-35 sensor that measures nostril temperature. [7] The parameters collected by respective sensors help us realize asthma monitoring, detection, and management.

The sensors that are used in the low-power wearable system can be divided into two parts: **environmental sensors**, including the ozone sensor (the commercial metal-oxide sensor—MICS2614, the atomic layer deposition-based sensor, and the temperature and humidity sensor—SI7023), and the volatile organic compounds (VOC) sensor; and **physiological sensors**, including the electrocardiogram (ECG) and the skin impedance sensor, the photoplethysmography (PPG) sensor, and the accelerometer—ADXL362. [8] The respective parameters are the ozone density, the

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temperature, the humidity, heart rate variability, the amount of VOCs, respiratory rates, and blood pressure, helping monitor, manage, and detect asthma.

As for the sensors used in wearable devices mentioned in the studies, they can be categorized as the liquid metal- based epidermal flexible sensor [9], the embroidered capacitive facemask sensor [5], the polymeric piezoresistive airflow sensor [10], the fabric-based humidity sensor [11], [the airflow sensor, the motion sensor, and the temperature sensor] [12], the photodetector [13], the wearable sensor for hydrogen peroxide (H_2O_2) measurement [14], the acoustic sensor [6], the integrated photo-sensor [4], [the temperature sensors and the highly sensitive strain sensor] [15], the wearable IoT aldehyde sensor [16], [the blood oxygen sensor, the temperature sensor, the humidity sensor, and the sensor to judge air quality] [7], [environmental sensors and physiological sensors] [8] and the novel monitoring device on asthma control [17] and [the temperature sensor, the commercially available contactless sensor and the acoustic sensor] [18].

The main part of the liquid metal-based epidermal flexible sensor is an electrode combined with SnS2 nanomaterials to become a wearable device that can sense different types of gases. [9]. The Bluetooth added to the device is used for monitoring and managing asthma remotely. Since respiratory rate as the parameter can be reflected by the amount of water vapor in the exhaled air, this sensor utilizes SnS2's feature that it can recover fast when contacting with water molecules.

The embroidered capacitive facemask sensor has been induced and analyzed in the specific systems' part above.

The polymeric piezoresistive airflow sensor is produced through nanocomposites produced and created by vertically grown graphene nanosheets, also called VGNs, and poly-dimethyl siloxane, also called PDMS. [10] This program uses airflow rates to reflect the parameter-respiratory rate, therefore helping promote the effectiveness to monitor asthma patients.

The vapor-coated conducting textile includes a face mask with a fabric-based humidity sensor in it, which is produced by the combination of fabrics made by cotton and a special material called a persistently p-doped conjugated polymer, poly (3,4-ethylenedioxythiophene): chloride (PEDOT-Cl) [11]. The air humidity that reflects respiratory rates changes when the people who wear it breathe. The signals, therefore, can be transduced into electrical signals by the humidity sensor with the help of the special mate- rial combination mentioned above. The monitoring process, therefore, can be realized.

The mask device for respiration tracking has the airflow sensor, Omron D6F–P MEMS sensor, utilized in conjunction with the Venturi tube for measuring respiratory flow rate, combined with another air flow sensor, Sensirion SFM3000 sensor, which is a reference to assess the mask device's analytical performance. [12] The MEMS motion sensor serves for orientation monitoring so as to make up for the pressure sensor signal drift as well as eliminate motion arti- facts through special algorithms used for gyroscope-assisted baseline tracking. [12] The parameters are respiratory rates, combined with the tidal volume and peak flow rates, which are collected through multiple sensors mentioned above, thus monitoring and managing asthma symptoms.

The wearable device mentioned for monitoring respiratory phases utilizes hybrid-based aspiration and respiration sensing (HARS). The microphone in the device is placed between the device and the chest skin, filtering breathing sounds from the patient's chest wall. The photoreflector plays a role in detecting the density of infrared light being reflected so that we can obtain the chest movement signal with clear boundaries. [13] Breathing phases are the main parameters in this study, which are the critical indicators for this study to monitor and detect asthma.

The wearable sensor mentioned in the study is used for measuring and monitoring exhaled H2O2 in artificial breath in real time. [14] It is quite clear that the key parameter collected in this study is the density of exhaled H2O2, which is a vital biomarker associated with asthma, thus being used to detect asthma.

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The acoustic sensor has been induced and analyzed in the specific systems' part above. The integrated photosensor has been induced and analyzed in the special platform's part above.

The smart bandage mentioned in the study has the strain sensor, which is wireless, temperature sensors, and is combined with a near-field communication tag, also called NFC, without a battery. The temperature sensor that monitors temperature variations in different scenarios and the highly sensitive strain sensor that focuses on the chest expansion during respiration are both produced through the special material: conductive poly (3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) polymer. [15] As for parameters, the respiratory volume collected by the strain sensor during the chest expansion as well as contraction processes, combined with body temperatures measured by the temperature sensors, can provide valuable data for detecting and monitoring asthma patients respiratory function and physical health.

The aldehyde sensor, which is based on IoT and is wearable, is used for measuring asthma patients' real-time exposure to aldehydes, which are types of airway irritants. After the sensor collects the data, the Android smartphone acts as a gateway to upload that data to the informatics system based on the cloud, handling storage, management, and analytics, thus realizing asthma management and monitoring. [16]

The blood oxygen sensor, the temperature sensor, the humidity sensor, and the air quality sensor have been induced and analyzed in the specific systems' part above.

The novel monitoring device on asthma control is de- signed and developed by Gecko Health. [17] Based on flow sensors and pressure sensors, the special sensor is attached to the top of the inhaler and can record each activation of the inhaled corticosteroid medication, thus promising asthma management and monitoring processes.

The smart inhaler called FindAir, the NuvoAir spirometer, and the Emfit QS + ACTIVE sleep monitor are analyzed in this study. [18] Related sensors include the temperature sensor that monitors the body temperature, the commercially available contactless sensor that monitors activity, heart rate, and respiration rate, and the acoustic sensor that measures respiratory sound features. All the above matters when it comes to asthma management, detection, and monitoring.

As for other kinds of methods mentioned in the studies, they can be categorized as the remote monitoring therapy [19], and the efficacy trial [20].

The remote monitoring therapy is actually a web-based interface used for monitoring remotely that is delivered to test the fractional FENO suppression, also called exhaled nitric oxide, thus reflecting severe asthma patients' response to inhaled corticosteroids (ICS). [19] The scores after finishing the asthma control questionnaire-5 and biomarker measurements, including FENO and peripheral blood eosinophil count, are the main parameters in this study, which judges whether the optimized ICS or the treatment with long-acting b2-agonist has clinical benefits or not. [19]

The Phase II/III trial, which is seamless, multi-site, and randomized, in this study is processed based on the scores resulting from the ACT tests, which include various patient- reported outcomes like symptom days and restricted activity days, thus helping asthma management. [20]

3. Results

From 1081 studies, we finally included 19 studies, which might partly represent the current development of the uses of special platforms or specific systems or the sensors used in wearable devices on asthma monitoring, detection, and management. Our scoping review summarizes special platforms (such as the nuvoAir platform, the Juli platform, and the unique respiratory rate measurement platform), which are mentioned in 3 out of 19 studies; specific systems (portable respiration monitoring system, wearable breathing sound monitoring system, etc.), which are mentioned in 4 out of 19 studies; sensors used in wearable devices (liquid metal- based epidermal flexible sensors and many others), which are mentioned in 15 out of 19 studies; as well as other

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methods (remotely monitored therapy and adaptive seamless pragmatic efficacy trials), which are 2 out of the 19 studies.

The most discussed parameter is the respiratory rate, which can be reflected by many different signals, followed by PEV, FEV1, FCV, the density of specific gas, breathing sounds, etc.

And about 16 different kinds of sensors are mentioned and used in the studies, which can be classified in their detection of sound, light, electricity, and heat related to asthma symptoms.

4. Discussion

During the process of collecting literature, we encountered numerous studies on asthma related to COVID-19. While it is evident that both COVID-19 and asthma are linked to pulmonary conditions, given the gradually diminishing impact of the novel coronavirus in the post-pandemic era, we did not prioritize these studies in our analysis in order to derive more generalized conclusions.

In reviewing existing research, we observed that some scholars have noted a potential link between asthma and allergic rhinitis. However, the specific mechanisms underlying this connection remain unclear, and no definitive quantitative relationship has been established. As a result, this area presents significant opportunities for further exploration. In the future, the application of sensors to monitor allergic rhinitis symptoms may allow for the prediction of asthma attacks.

Another issue frequently highlighted in multiple studies is medication adherence. Medications used to alleviate asthma symptoms may lead to dependency or have adverse effects on patients' health. Exploring ways to mitigate or eliminate these side effects is undoubtedly a subject that warrants deeper investigation. Research on wearable devices in this domain is also ongoing.

Moreover, many studies have applied deep learning techniques to monitor the regularity of patients' breathing, aiming to determine whether they are experiencing asthma attacks. This approach could assist physicians in identifying the symptoms and severity of asthma attacks, offering strong support for the development of telemedicine and significantly reducing the caregiving burden on healthcare professionals.

5. Conclusion

This scoping review induced and analyzed 19 studies on special platforms, specific systems, and the sensors used in wearable devices for asthma. Through the present technologies used, future research could explore more links between asthma and different sensors, more systems and platforms that help asthma patients, and more chances to utilize deep learning for breathing monitoring. This scoping review pro- vides quite a lot of information, references, and analysis bases for future asthma-related research and practice.

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Chen Yiyang and Du Xinchen contributed equally to this work and should be considered co- first authors.

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