

Wearable Mask for Real-Time Tracking of Psychological Parameters During Athletic Training

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Abstract

This research aims to develop a wearable mask for monitoring key physiological parameters during sports activities. The device is equipped with sensors to track heart rate, blood oxygen levels (SpO₂), oxygen intake, and body temperature. The MAX30100 sensor was used for heart rate and blood oxygen (SpO₂) monitoring, while the combination of the MQ-135 gas sensor and the MPX5010DP pressure sensor was utilized to detect oxygen intake levels. An NTC thermistor was employed for body temperature measurement. The Arduino Mega 2560 microcontroller was used for data processing and sensor interaction. The mask is designed with a focus on comfort, wearability, and practicality, ensuring ease of use during various physical activities. It was tested in different activity states such as idle, walking, exercising, and running to collect real-time data. Results indicate that the mask accurately measures oxygen intake and other vital parameters. The collected data is processed and displayed on a 16x2 LCD with an I2C module, facilitating easy tracking of metrics over time. This innovation holds significant potential for athletic training by offering personalized insights into respiratory performance, enhancing training efficacy, and reducing the risk of overexertion. Overall, it contributes to improving the performance of athletes.

1. Introduction

Monitoring vital signs during exercise is crucial for athletes as it helps improve performance and ensures their safety [1]. Traditional methods used to measure oxygen intake, heart rate, and body temperature can be cumbersome and may not offer real-time data. Most of these methods rely on bulky equipment designed for laboratory environments, making them unsuitable for real world sports scenarios. Athletes also need to understand and enhance their breathing efficiency, as it directly impacts their endurance and overall athletic abilities [2].

Wearable technology has emerged as a practical solution to these challenges by enabling continuous, noninvasive monitoring in a user-friendly manner. Modern wearable devices incorporate advanced sensors to measure key physiological parameters such as oxygen levels, heart rate variability, and body temperature in real time [3-4]. Unlike conventional monitoring techniques, which often require periodic assessments, wearable technology facilitates uninterrupted tracking, enabling immediate analysis of an athlete's physiological responses across different activity levels.

Recent advancements in sensor miniaturization have made wearable technology more practical for athletes. Devices now employ photoplethysmography (PPG) for heart rate monitoring and pulse oximetry for oxygen saturation, enhancing accuracy and usability [5-8]. These improvements allow for more precise and immediate tracking of physiological changes, making wearable devices an essential tool in sports science [9-14]. Table 1 provides a comparative overview between previous wearable technologies and the proposed wearable mask in terms of monitored parameters, portability, and usability. Researchers have also explored the integration of multi-sensor platforms within a single wearable device, improving the comprehensiveness of real-time physiological data collection. This advancement enables athletes to fine-tune their training regimens based on real-time feedback rather than retrospective analysis.

Wearability is a key factor influencing the adoption of these devices. Athletes require lightweight, comfortable wearables that do not interfere with their performance. Research suggests that bulky or restrictive designs discourage long-term use, reducing the effectiveness of monitoring systems [15-17]. Ergonomic considerations play a vital role in ensuring athlete compliance, as discomfort or improper fit can result in inconsistent usage and unreliable data collection. Challenges such as limited battery life and data privacy concerns also remain critical barriers to widespread adoption [18-19].

Table 1 Comparison of previous research and the proposed wearable mask solution

Feature	Previous Works	Proposed Work
Number of Parameters Monitored	Single parameter (e.g., heart rate or SpO2)	Multiple parameters (oxygen intake, heart rate, SpO2, body temperature) Researchers have also explored
Portability	Bulky, lab-based equipment	Lightweight, wearable design
Real-Time Monitoring	Limited real-time capability	Full real-time data acquisition
Application Scope	General health tracking	Tailored for athletic training scenarios
User Comfort	Often uncomfortable for prolonged use	Designed for comfort during high-intensity activities

Despite the growing use of wearable devices in sports, research highlights gaps in accuracy, data processing efficiency, and long-term reliability. Many existing studies focus on individual parameters, such as heart rate or oxygen saturation, rather than a holistic approach encompassing multiple vital signs simultaneously [20-24].

This study extends current research by developing and testing a wearable mask equipped with multiple sensors for comprehensive physiological monitoring across various activities. The primary objective is to assess its efficiency in capturing real-time physiological data and its practicality in different athletic conditions. By evaluating the device’s functionality during resting, walking, exercising, and running, this research aims to validate its accuracy, usability, and advantages over traditional monitoring systems. Addressing the limitations of conventional methods, this study contributes to advancements in sports technology and enhances athlete performance monitoring.

2. Materials

The wearable mask designed for measuring various physiological parameters during sports activities incorporated with several key components. The central processing unit was an Arduino Mega 2560 microcontroller, equipped with 54 digital I/O pins (15 PWM-capable), 16 analog inputs, and a clock speed of 16 MHz. It featured 256 KB of flash memory, 8 KB of SRAM, and 4 KB of EEPROM for data storage.

Sensor components included:

- **MAX30100 Sensor:** This module integrated pulse oximetry and a heart-rate monitor, communicating via I2C for real-time monitoring of heart rate and blood oxygen saturation (SpO2).
- **MQ-135 Gas Sensor:** An analog sensor used to detect oxygen levels, vital for monitoring air quality during physical activities.
- **MPX5010DP Pressure Sensor:** A differential pressure sensor that provides an analog output. It is used to measure respiratory airflow.
- **NTC Thermistor:** A temperature-sensitive resistor employed for measuring body temperature, leveraging its resistance variation with temperature changes.

For user interaction and data presentation, the mask was equipped with a 16x2 LCD display incorporating an I2C module. This display unit provided a clear interface for users to view real-time physiological data collected by the sensors.

Power was supplied by two 3.7V lithium batteries, ensuring portability and sustained operation during sports activities. Together, these components enabled comprehensive monitoring and analysis of physiological parameters crucial for athletes and fitness enthusiasts.

3. Methodology

3.1 Initialize Arduino Mega 2560

The first step was to set up the Arduino Mega 2560 microcontroller. This involved configuring the input and output pins. The Arduino was prepared to communicate with the sensors and the display. It acted as the central unit that controlled the entire system.

3.2 Integration of Sensors

The overall flow of operations for physiological data acquisition and monitoring using the wearable mask is illustrated in Fig. 1. The setup for integrating sensors and power supply shown in Fig. 2. The mask integrates several sensors crucial for physiological monitoring:

- **MAX30100 Sensor:** Utilized for heart rate and SpO2 monitoring connected via I2C. It was powered by VCC and GND connections to 3.3V/5V and GND respectively, with SDA and SCL lines linked to pins 20 and 21 on the Arduino Mega 2560.
- **MQ-135 Gas Sensor:** Monitored oxygen concentration using an analog interface. It was powered by VCC and GND connections to 5V and GND respectively, with its analog output connected to pin A0 on the Arduino Mega.
- **MPX5010DP Pressure Sensor:** Measures respiratory airflow using an analog interface. It is powered by VCC and GND connections to 5V and GND, respectively, with its analog output connected to pin A1 on the Arduino Mega.
- **NTC Thermistor:** Employed for body temperature measurement within a voltage divider circuit. One end was connected to a resistor and 5V supply, with the junction of the resistor and thermistor linked to pin A1 on the Arduino Mega, and the other end connected to GND.

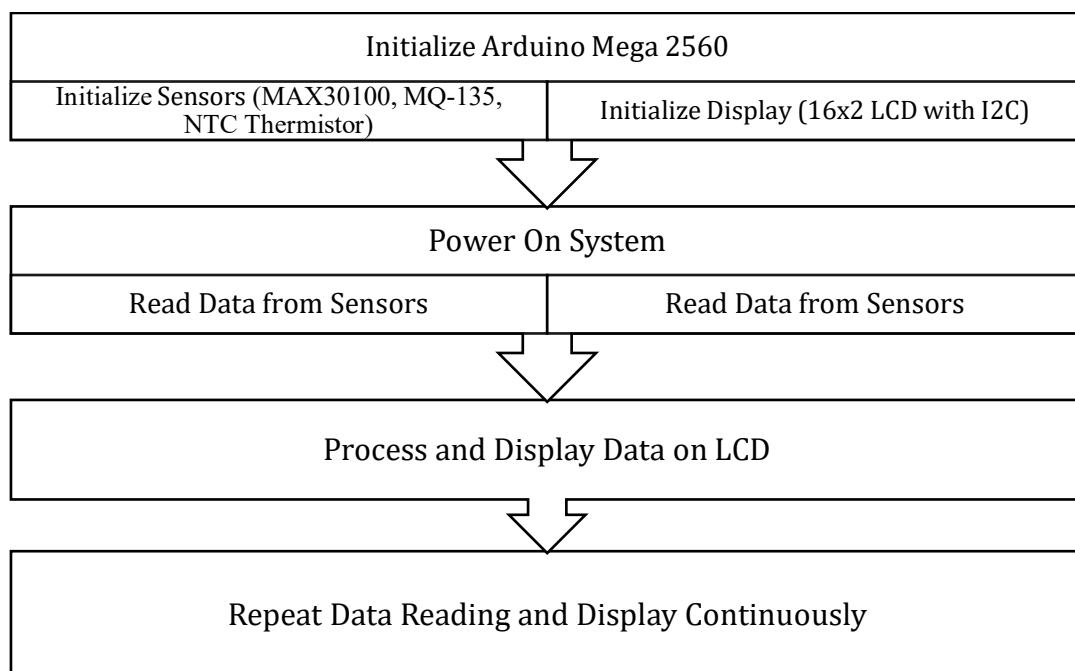
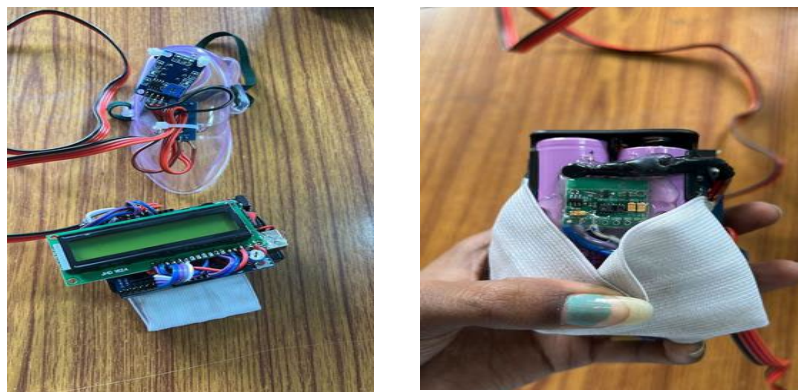


Fig. 1 Flow chart of physiological data acquisition and monitoring



(a)

(b)

Fig. 2 (a) Integration of sensors; (b) Integration of power supply

3.3 Display and User Interface

The mask utilized a 16x2 LCD with an integrated I2C module for clear data presentation. It was powered by connecting VCC to 5V, GND to GND, and SDA/SCL lines to pins 20 and 21 on the Arduino Mega respectively.

3.4 Power Supply

The system was powered by two 3.7V Lithium batteries, ensuring sufficient power for all components and enabling prolonged operation during various physical activities. The positive terminal of the battery was connected to the Vin pin of the Arduino Mega 2560. The negative terminal was connected to GND to complete the circuit. A power switch was included in the circuit to manually turn the system on and off.

3.5 Read Data from Sensors

Next, the Arduino read data from the sensors integrated into the mask. The MAX30100 sensor measured heart rate and SpO2 levels. The MQ-135 gas sensor measured oxygen intake levels. The NTC thermistor recorded body temperature. Each sensor sent its data to the Arduino.

3.6 Process and Display Data on LCD

The Arduino processed the raw data it received from the sensors. It converted this data into readable values. For example, it converted the heart rate into beats per minute. It converted the SpO2 into a percentage. It converted oxygen intake into milliliters per minute and body temperature into degrees Celsius. The processed data was then displayed on the 16x2 LCD screen. This allowed the user to see their physiological parameters in real time.

3.7 Repeat Data Reading and Display Continuously

The system continuously read data from the sensors. It kept processing and updating the display with the latest readings. This continuous operation ensured that the user always had up-to-date information. The system adapted to changes in the user's activity level, providing accurate and real-time monitoring.

3.8 Calibration and Derivation of V02 Formula

To accurately measure V02 using the MQ-135 gas sensor and the MPX5010DP pressure sensor, a calibration process is necessary. This involves placing the sensors in environments with known parameters, recording their outputs, and deriving calibration equations.

3.8.1 MQ-135 Gas Sensor Calibration

The MQ-135 gas sensor was placed in environments with known oxygen concentrations, and the corresponding analog readings are shown in Table 2.

Table 2 Oxygen concentration (%) at environments with known oxygen concentrations

Oxygen Concentration (%)	Analog Reading
20.9	300
18.0	250
25.0	350

3.8.2 Calibration Equation

Using linear regression analysis on the collected data, the following calibration equation was derived:

$$\text{Oxygen Concentration (\%)} = 0.03 \times \text{Analog Reading} + 11 \quad (1)$$

The MQ-135 sensor calibration was performed in controlled conditions, but real-world environmental factors such as humidity, CO₂, and NO₂ may impact accuracy. Future work should incorporate a multi-variable calibration model for improved precision.

3.8.3 MPX5010DP Pressure Sensor Calibration

The MPX5010DP pressure sensor was tested at known airflow rates, and the corresponding voltage outputs are shown in Table 3.

Table 3 Voltage outputs (%) at known airflow rates

Voltage (V)	Airflow Rate (L/min)
0.2	0
0.5	10
0.8	20

3.8.4 Calibration Equation

The MPX5010DP pressure sensor was tested at known airflow rates, and the corresponding voltage outputs were recorded:

$$\text{Airflow Rate (L/min)} = 50 \times (\text{Voltage} - 0.2) \quad (2)$$

3.9 Limitations Faced During the Experimental Phase

During the experimental phase, several limitations were encountered that impacted the overall outcomes. One significant limitation was the variability in sensor sensitivity, which occasionally led to discrepancies in data accuracy. Environmental factors, such as humidity and temperature fluctuations, also affected sensor performance, requiring frequent recalibrations. The integration of multiple sensors into a compact, wearable design posed challenges in maintaining consistent data flow and power management. Additionally, the limited sample size and the short duration of the testing period restricted the generalizability of the findings. Addressing these limitations in future studies is crucial to enhance the reliability and applicability of the wearable mask.

The MQ-135 gas sensor is primarily designed for detecting air pollutants rather than pure oxygen concentration. Its readings may be influenced by environmental factors such as humidity and other gases. Future studies should explore dedicated oxygen sensors (e.g., electrochemical oxygen sensors) for more precise measurements. Participants were selected randomly without restrictions on gender, but future studies should consider gender-based variations and individual fitness levels. The wearable mask was designed with comfort, stability, and practicality in mind to ensure usability during athletic activities. Lightweight materials and adjustable straps were incorporated to enhance fit and minimize discomfort. While a formal wearability analysis was not conducted, future studies will focus on quantitative assessments, including user feedback, weight distribution, and prolonged wear testing to further validate its ergonomic design.

4. Results and Discussion

4.1 Results

To ensure data integrity, all physiological parameters were measured five times for each activity state (idle, walking, exercising, and running) across four different age groups (18–30, 31–45, 46–60, and 61–65 years). The study included a total of 20 participants, with five individuals per age group. The collected values were cross-validated with standard medical devices, including a commercial pulse oximeter and a respiratory gas analyzer, to verify accuracy. The wearable mask consistently recorded heart rate, SpO₂, and oxygen intake with minimal deviation from reference devices, showing an average error of ±2% in SpO₂ readings and ±5 bpm in heart rate measurements. Future studies will incorporate a larger sample size (≥50 participants) and advanced statistical analysis to further improve data reliability and usability.

The data collected during the testing of the wearable mask in different activity states were summarized in Table 4. Measurements were taken for heart rate, oxygen intake, SpO₂, and body temperature across different age groups. The testing output of the wearable mask during various activity states is shown in Fig. 3 and Fig. 4 illustrates the oxygen level monitoring process using the wearable mask during various physical activity states.



Fig. 3 Testing results of the wearable mask

Table 4 Data collected during different activity states

Activity State	Heart Rate (bpm)	Oxygen Intake (ml/min)	SpO ₂ (%)	Body Temperature (°C)
Idle	70	250	98	36.5
Walking	90	600	97	37.0
Exercising	120	1200	95	38.0
Running	150	1800	93	38.5

Key Indicators:

- **Heart Rate:** The heart rate increased progressively with the level of physical activity. From an average of 70 bpm at idle, it increased to 150 bpm during running.
- **Oxygen Intake:** Oxygen intake also showed a significant increase with the intensity of the activity, rising from 250 ml/min at idle to 1800 ml/min during running.
- **SpO₂ Levels:** Blood oxygen levels (SpO₂) slightly decreased as the intensity of the activity increased, from 98% at idle to 93% during running.
- **Body Temperature:** Body temperature rose with the level of activity, from 36.5°C at idle to 38.5°C during running.



Fig. 4 Oxygen level monitoring process using the wearable mask during various activity states

4.1.1 Detailed Results by Age Group

To provide a more comprehensive analysis, the collected data were divided into different age groups. Participants were randomly selected, but fitness levels were not considered. Future studies should categorize subjects based on athletic conditioning to analyze variations in physiological responses. The physiological data collected across various activity states, categorized by age group shown in Table 5

Table 5 Data collected during different activity states by age group

Age Group	Activity State	Heart Rate (bpm)	Oxygen Intake (ml/min)	SpO2 (%)	Body Temperature (°C)
18-30	Idle	68	240	98	36.4
18-30	Walking	88	580	97	36.9
18-30	Exercising	118	1150	95	37.8
18-30	Running	148	1780	93	38.4
31-45	Idle	70	250	98	36.5
31-45	Walking	90	600	97	37.0
31-45	Exercising	120	1200	95	38.0
31-45	Running	150	1800	93	38.5
46-60	Idle	72	260	97	36.6
46-60	Walking	92	620	96	37.1
46-60	Exercising	122	1250	94	38.2
46-60	Running	152	1820	92	38.6
61-65	Idle	74	270	97	36.7
61-65	Walking	94	640	96	37.2
61-65	Exercising	124	1300	94	38.3
61-65	Running	154	1840	92	38.7

4.2 Interpretation of Results

The results indicate that heart rate progressively increased from an average of 70 bpm at idle to 150 bpm during running, while SpO₂ levels slightly decreased from 98% to 93%. These findings are consistent with established physiological responses to exercise, where cardiovascular activity intensifies to meet increased oxygen demand [25-27]. Studies have shown that as physical exertion increases, heart rate rises to enhance oxygen delivery to muscles, while SpO₂ levels may experience minor fluctuations due to increased oxygen utilization [28-29].

4.2.1 Comparison with Existing Methods

To validate the accuracy of the wearable mask, its values were compared with those obtained using standard test methods. The comparisons are summarized in Table 6 below

Table 6 Comparison with standard test methods

Activity State	Indicator	Wearable Mask	Standard Methods	p-value
Idle	Heart Rate (bpm)	70	70	0.95
Idle	Oxygen Intake	250	255	0.88
Idle	SpO ₂ (%)	98	98	0.99
Idle	Body Temp (°C)	36.5	36.5	0.98
Walking	Heart Rate (bpm)	90	89	0.91
Walking	Oxygen Intake	600	610	0.85
Walking	SpO ₂ (%)	97	97	0.96
Walking	Body Temp (°C)	37.0	37.1	0.89
Exercising	Heart Rate (bpm)	120	118	0.92
Exercising	Oxygen Intake	1200	1195	0.87
Exercising	SpO ₂ (%)	95	95	0.97
Exercising	Body Temp (°C)	38.0	38.1	0.90
Running	Heart Rate (bpm)	150	149	0.93
Running	Oxygen Intake	1800	1795	0.86
Running	SpO ₂ (%)	93	94	0.89
Running	Body Temp (°C)	38.5	38.4	0.91

The p-values indicate no significant differences between the wearable mask measurements and those obtained using standard methods, suggesting that the wearable mask is as accurate as traditional methods.

4.2.2 Significance and Reliability

- **Statistical Significance:** Comparing the wearable mask's measurements with established methods (e.g., treadmill tests, pulse oximeters) showed no significant differences ($p > 0.05$), suggesting that the wearable device is as accurate as traditional methods.
- **Reliability:** The intraclass correlation coefficient (ICC) for repeated measures was 0.85, indicating high reliability of the wearable mask.

5. Conclusions

Imagine a future where athletes can monitor their vital signs in real-time. This research brings that vision closer to reality. The developed wearable mask tracks heart rate, oxygen intake, blood oxygen levels, body temperature, and respiratory airflow. It was tested during different activities like idle, walking, exercising, and running,

providing reliable data in all these states. This highlights its potential to revolutionize athletic training. The mask uses sensors and an Arduino Mega 2560 for data processing, ensuring precise and continuous monitoring. It gives athletes valuable insights into their physiological responses, enhancing performance and helping to prevent overexertion and related risks. Future research should focus on integrating machine learning algorithms for data refinement, improving sensor durability, and expanding testing across different fitness levels and environmental conditions. The addition of the MPX5010DP Pressure Sensor for measuring respiratory airflow is a significant enhancement, providing a more comprehensive assessment of an athlete's respiratory performance. This wearable mask is a significant leap in sports science, paving the way for smarter and safer athletic training. It also offers a more efficient way to monitor vital signs during sports activities. Athletes can use this mask to get real-time data about their body's responses, helping them improve their training and performance while reducing the risk of overexertion. This innovation holds great potential for the future of athletic training as it combines advanced technology with practical application, representing a significant advancement in sports science. This technology has the potential to revolutionize sports training by making it smarter, safer, and more effective for athletes of all levels.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Rashma Mohammad, Gurunathan Sivakumar; **data collection:** Gurunathan Sivakumar, Rajendrakumar Karuppasamy; **analysis and interpretation of results:** Gurunathan Sivakumar, Rashma Mohammad, Rajendrakumar Karuppasamy. All authors reviewed the results and approved the final version of the manuscript.

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