


## RESEARCH ARTICLE

# Advancing tele-physiology: A chest patch solution for continuous, non-invasive remote monitoring in a hypoxic environment

Danilo Bondi<sup>1</sup>  | Ferdinando Calcagno<sup>2,3</sup>  | Elisa Fioraso<sup>3,4</sup> | Camillo Di Giulio<sup>5</sup>  | Federico Schena<sup>3,4</sup> | Anna Pedrinolla<sup>4,6</sup>

<sup>1</sup>Department of Neurosciences, Imaging and Clinical Sciences, University 'G. d'Annunzio' Chieti - Pescara, Chieti, Italy

<sup>2</sup>Department of Engineering for Innovation Medicine, University of Verona, Verona, Italy

<sup>3</sup>Department of Neurosciences, Biomedicine and Movement Sciences, University of Verona, Verona, Italy

<sup>4</sup>Sport, Mountain and Health Research Centre (CeRISM), University of Verona and University of Trento, Rovereto, Italy

<sup>5</sup>Department of Science, University "G. d'Annunzio" Chieti - Pescara, Chieti, Italy

<sup>6</sup>Department of Cellular, Computational and Integrative Biology (CIBIO), University of Trento, Trento, Italy

## Correspondence

Danilo Bondi, Department of Neurosciences, Imaging and Clinical Sciences, University "G. d'Annunzio" Chieti - Pescara, Via dei Vestini, 31, 66100, Chieti, Italy.  
Email: [danilo.bondi@unich.it](mailto:danilo.bondi@unich.it)

Handling Editor: Edward Ashworth

## Abstract

Skin-mounted sensors are thin, flexible and lightweight electronic devices that enable monitoring of multiple physiological parameters. The aim of this study was to provide pilot evidence for possible utilization of a sensorized patch for capturing the bodily response to hypoxia. The subsequent phases of the study comprised a case report and a case series, with participants undergoing physical tests in both normobaric normoxia and hypoxia. The data obtained from VitalPatch® were compared with data from the metabolic cart COSMED Quark CPET. In the case report, agreement was substantial for heart rate (HR) and poor for respiratory rate (RR) in an incremental normoxic test, and almost perfect for HR and moderate for RR in a time-to-exhaustion hypoxic test; in the case series, agreement was substantial for HR and poor for RR. The trend of values generally was almost superimposable and mean bias was overall acceptable. ECG alarms were considered mostly false or highly uncertain, possibly due to noise and artifacts. The quality of the recording was unaffected by the presence of hypoxia. VitalPatch® is best used at rest and in minimal movement, offering reliable HR and RR monitoring.

## KEYWORDS

chest patch, high-altitude, normobaric hypoxia, remote monitoring, skin-mounted sensors, telemedicine, wearable sensors

## 1 | INTRODUCTION

High-altitude expeditions are a large growth sector, whether for tourism, business or sports purposes. To enable high-risk patients

to fully enjoy the experience while mitigating risks, and generally to improve the safety of those who expose themselves to such hypoxic environments, the use of reliable sensors for remote monitoring could be of enormous value. By using wearable/portable sensors and Internet of Things (IOT) technology, it is currently possible to obtain real-time data of physiological characteristics of expeditioners, their positions and the features of the surrounding environment, thereby enabling continuous monitoring and timely communication, reducing response times and increasing safety in challenging and

Declaration of Generative use of AI: During the preparation of this work the authors used Google Colab notebook to execute Python code in the browser, and the associated functions of Google Gemini AI to generate part of the Python code and edit the final draft of the code. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

This is an open access article under the terms of the [Creative Commons Attribution](https://creativecommons.org/licenses/by/4.0/) License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2026 The Author(s). *Experimental Physiology* published by John Wiley & Sons Ltd on behalf of The Physiological Society.

remote locations (Donavalli et al., 2024; Thendral et al., 2024). Such sensors should ensure duration, portability and ease of handling by the subject, robustness and resistance to harsh conditions, automatic alarms, data handling, and comprehensive reports. The real time data-processing of vast amounts of data generated by advanced biosensors enables anomaly detection, timely interventions and personalized health insights (Raymond et al., 2024). Physiological datasets of several research topics need expansion into real-world environments, with cost-effective devices that can be utilized even with no specialized knowledge (Cobá Juárez Pegueros & Rodríguez-Arce, 2025).

Due to their non-invasive nature and the possibility of continuous, real-time data acquisition and analysis, sensorized patches with embedded biosensors have gained growing attention for remote health monitoring, fitness monitoring and medical research (Mali et al., 2023). These devices, also known as skin-mounted sensors, are thin, flexible and lightweight electronic devices that adhere directly to the skin and can integrate a variety of biosensing technologies, thereby allowing monitoring of several physiological parameters. However, these biosensors are usually utilized in stationary setting with patients, and performance criteria during body movement or outdoor environments are scarce (Areia et al., 2021). More demanding challenges and limitations of using wearable sensors in unusual or extreme environment create issues of accuracy and reliability of measurement, signal quality, motion artifacts, comfort and usability, integrity and transmission of data, user acceptance, power consumption and battery life (Chen et al., 2023; Liu et al., 2024; Shen et al., 2020).

Given the growing number of individuals travelling to high altitudes, sensorized patches in this extreme environment would be highly useful. Indeed, these biosensors reduce human-related limitations and challenges of wearable sensors in extreme environments, such as discomfort and direct exposure to the external environment, but technical challenges may limit their use. Indeed, exposure to cold temperatures, hypobaria, UV radiation, low humidity, special clothing, dirt, sweat, interferences and body movements are all likely to affect the devices' functions. The operating conditions of one such device, VitalPatch®, are as follows: temperature range of 0–40°C, storage relative humidity range of 10–95%, operating duration of 120–168 h, altitude < 3000 m, and barometric pressure of 525–765 mmHg.

Therefore, this study aimed to create pilot evidence for using VitalPatch® to capture the bodily response to hypoxia exposure and for adopting this small (120 mm x 41 mm x 9.5 mm) and light (13 g) sensorized patch during subsequent high-altitude studies.

## 2 | METHODS

### 2.1 | Study details

#### 2.1.1 | Design of the study

This pilot study included two highly stressful physical tests, that is, incremental and time-to-exhaustion, in both normobaric normoxia and

#### Highlights

- **What is the central question of this study?**  
Can a sensorized patch accurately capture the bodily response to hypoxia during physical exercise?
- **What is the main finding and its importance?**  
The VitalPatch® sensor is suitable for field applications under hypoxic conditions, but the presence of motion artifacts still limits its use during hypoxic exercise.

normobaric hypoxia. We conducted the study in two phases: (1) the first on one participant, before and after a high-altitude expedition (case report); (2) the second, on four other ad hoc recruited participants who underwent the test sessions on two separate days, interspersed with a day of rest (case series). In all cases, the sensor was kept for at least 2.5 days, from the beginning of the tests in normoxia to the end of the tests in hypoxia; given the availability of participants, it was also kept on the following days until the battery was exhausted.

A physician was present during all exercise tests to ensure participant safety and to provide clinical oversight throughout the protocol. All recorded traces and alarms reported from VitalPatch® (hereinafter referred to as VITALPATCH) were analysed offline by separate physicians with expertise in sports cardiology who were not present during the experimental sessions; the evaluators were blinded to the experimental setting.

#### 2.1.2 | Ethical approval

Participants signed their written informed consent. The protocol was approved by the Ethics Committee of the University of Trento (protocol no. 2025–038) and conformed to the 2013 revision of the *Declaration of Helsinki*.

## 2.2 | Participants

### 2.2.1 | Case report

A 37-year-old male (height: 170 cm; weight: 65 kg;  $\dot{V}_{O_{2max}}$ : 46.7 mL/min/kg) was included in this case report. At the age of 28, he developed a severe form of meningitis complicated by meningococcal sepsis, septic shock and purpura fulminans, resulting in the amputation of both lower limbs and seven fingers. One year later, he began running with carbon fiber prosthetic blades, and the following year he resumed mountaineering with the aid of specialized prosthetics. He achieved a progressive increase in altitude, reaching the summit of Mount Everest. The subject visited the laboratory twice, completing the four experimental sessions before and after a 15-day expedition, during which he successfully reached the summit of Mount Denali (6190 m;

formerly Mount McKinley, Alaska, USA). The participant wore the body patch before the expedition, during the incremental test in normoxia and in the following days, and after the expedition, during the time-to-exhaustion test in hypoxia and in the following days.

## 2.2.2 | Case series

The participants were recruited from among mountain guides or aspiring mountain guides who underwent testing at the Sport, Mountain and Health Research Centre (CeRiSM, Rovereto, Italy) to obtain relevant information about their health and fitness in relation to their work. The sex distribution of this type of worker is notoriously very asymmetrical, with almost all of them being male. Four healthy male subjects were included in the case series (age:  $42.0 \pm 2.4$  years; height:  $177.3 \pm 5.4$  cm; weight:  $76.0 \pm 9.4$  kg;  $\dot{V}_{O_2\max}$ :  $50.2 \pm 8.0$  mL/min/kg). All participants were well-trained and had experience with high-altitude environments, including various expeditions above 5000 m.

## 2.3 | Procedures

### 2.3.1 | Normobaric normoxia and normobaric hypoxia

Both experimental sessions were conducted in an environmental chamber designed to simulate high-altitude exposure (i.e., normobaric hypoxia). The normoxic condition was established by maintaining ambient air without altering the oxygen concentration (20.9%). The hypoxic condition was set over the reported operating range of VitalPatch® (i.e., <3000 m altitude) and was achieved by reducing the oxygen concentration to 11.3% using an oxygen dilution system based on the vacuum pressure swing adsorption principle (B-Cat, Tiel, The Netherlands), simulating an altitude of approximately 5000 m above sea level. Temperature was maintained at  $22.0 \pm 0.5^\circ\text{C}$  using a dedicated air conditioning and refrigeration system (Frigotherm Ferrari SRL, Lana, Italy). Relative humidity was set at 40% in both conditions.

### 2.3.2 | Incremental test

The incremental test was performed on a reclined cycling ergometer (Ergoselect 1200, Ergoline GmbH, Bitz, Germany) and consisted of two phases. The first phase included several 4-min bouts with 2 min of rest between each bout. Starting at 50 W, the workload was increased by 25 W at each consecutive bout until the subject reached a blood lactate concentration of 4 mmol/L. Once this point was reached, the subject rested for 5 min. Immediately afterward the second phase started, and a ramp test was performed, starting from the workload corresponding to the bout preceding the 4 mmol/L threshold. During the ramp test, the intensity was increased by 25 W every minute until exhaustion.

### 2.3.3 | Time-to-exhaustion test

The time-to-exhaustion test was performed on the same reclined cycling ergometer used for the incremental test. The test intensity was set at 80% of the  $\dot{V}_{O_2\max}$  determined from the incremental test. After a 3-min warm-up at 35–40% of  $\dot{V}_{O_2\max}$ , the workload was immediately increased to 80%, and the subject was instructed to maintain a cadence between 80 and 90 rpm until exhaustion. The research staff provided strong verbal encouragement throughout the test. Exhaustion was defined as the point at which the subject was unable to maintain the target cadence despite continuous encouragement.

## 2.4 | Instruments

### 2.4.1 | Metabolimeter

Both incremental and time-to-exhaustion tests were performed using a metabolic cart (Quark CPET, COSMED, Rome, Italy) integrated with a 12-lead electrocardiogram (ECG) system. The device measures breath-by-breath gas exchange parameters through a mask, including oxygen uptake ( $\dot{V}_{O_2}$ ), carbon dioxide production ( $\dot{V}_{CO_2}$ ), minute ventilation ( $\dot{V}_E$ ) and respiratory exchange ratio (RER), with real-time data acquisition. Prior to each test, the system was calibrated using reference gases and a 3-L syringe according to the manufacturer's specifications. ECG monitoring was conducted continuously throughout the test to assess cardiac electrical activity and detect potential arrhythmias or ischaemic changes.

### 2.4.2 | Sensorized patch

The remote monitoring was performed by using a sensorized patch, that is, VitalPatch® (VitalConnect, Inc., San Jose, CA, USA), a wireless, single-use, battery-operated biosensor attached on the upper left chest. It allowed recording of electrocardiography (ECG), temperature and activity, thereby computing the R-R interval, heart rate (HR) variability, respiratory rate (RR), step count, body posture and fall detection. The device allows registration of data for up to 7 days, with the following measurement ranges: ECG from  $-10$  to  $10$  mV, HR from 30 to 200 bpm, RR from 4 to 42 bpm (Mean Absolute Error, MAE < 1.5 bpm) and body temperature from  $32^\circ\text{C}$  to  $42^\circ\text{C}$  (MAE <  $1^\circ\text{C}$ ). An additional adhesive overlay was applied. Data collected were continuously transmitted to a dedicated online platform via a Bluetooth-paired smartphone. The sensor was developed for the purpose of remote monitoring of patients.

## 2.5 | Data analysis

### 2.5.1 | Case report

Before the expedition, data registered during the normoxic incremental tests were checked and aligned by starting time. Although

the volunteer reached values of RR and HR around 80 and 180 rpm, respectively, the VITALPATCH device is calibrated to obtain values up to the threshold of 42 breaths per minute, that is, any actual value above 42 bpm is incorrectly interpreted by the system as 42 bpm. Consequently, the final two steps of the incremental test were excluded from the subsequent device comparison, leaving 31 min of recording. Data from both COSMED and VITALPATCH were filtered by using a locally weighted scatterplot smoothing (LOWESS) method, with fine smoothing (20 points in smoothing window), to obtain uniformly 22,644 points (i.e.,  $f \approx 12.17$  Hz) despite the diverse sampling frequencies of the raw data between the devices. Once back from the expedition, data registered during the hypoxic time-to-exhaustion test were checked and aligned, then values over 42 breaths/min were excluded thereby leaving 5 min and 33 s of recording; data were filtered with fine LOWESS to obtain uniformly 4324 points (i.e.,  $f \approx 12.98$  Hz). Data filtering and calculation of mean bias and area under curve (AUC) were carried out with the software GraphPad Prism v. 10.1.1 (GraphPad Software, Boston, MA, USA); Lin's CC calculation (Lin, 1989), along with scale shift, effect size and accuracy, was carried out with the online tool available at <https://www.statstodo.com/LinCCC.php>. The other correlation measures were obtained by using the software Jamovi v. 2.3.21.0. Before the expedition, from the day between hypoxic and normoxic tests onwards for another 4 days, and after the expedition, from the day of hypoxic test onwards for another 5 days, ECG data from VITALPATCH were analysed through the linked systems *MediBioSense HealthStream* and *ViewECG v.1.1.6*, thus obtaining 24-h reports of ECG and Heart Rate Variability (HRV) to be downloaded. Atypical episodes from ECG reports were checked.

## 2.5.2 | Case series

The case report was used to identify a feasible approach for further analysis in a case series. To this extent, data registered from COSMED and VITALPATCH were processed with Python, by applying the following steps:

- extraction of data and alignment by time, with an iterative approach supported by visual check;
- imputation of VITALPATCH data with a LOWESS filter (cubic, usually 0.001 fraction);
- applying a third-order Savitzky–Golay filter with adjustable window (usually 10–15);
- resampling data with  $f = 1$  Hz with a linear filter;
- applying a third-order Savitzky–Golay filter;
- extracting 25 min for the incremental test and 5 min for the TTE test, with an iterative approach supported by visual check and considering the maximum threshold of 42 bpm for RR computed by VITALPATCH system;
- computing AUC, Spearman's correlation coefficient  $\rho$  with  $P$ -value, Lin's CCC, mean bias and limits of agreement (LoA;  $\pm 1.96 \times \text{SD}$ );
- graphing pairwise comparison by highlighting the difference area

**TABLE 1** Comparison of data registered from COSMED and VITALPATCH devices during the normoxic incremental test, before the expedition.

|             |                  | HR            | RR            |
|-------------|------------------|---------------|---------------|
| Bias        | Mean (COS – VIT) | –2.627        | –0.260        |
|             | 95% LoA          | –10.58, 5.323 | –4.920, 5.439 |
| AUC         | COS              | 20,3516       | 51,843        |
|             | VIT              | 208,402       | 51,360        |
| Precision   | $r$              | 0.989         | 0.894         |
|             | $\rho$           | 0.989         | 0.872         |
|             | $\tau$           | 0.920         | 0.688         |
| Scale shift | $\omega$         | 0.990         | 1.276         |
| Effect size | $v$              | 0.098         | 0.051         |
| Accuracy    | $\chi_a$         | 0.995         | 0.970         |
| Lin's CCC   | $\rho_c$         | 0.984         | 0.867         |
|             | 95% CI           | 0.983, 0.984  | 0.864, 0.869  |

All correlation measures were statistically significant with  $P < 0.001$ . Abbreviations: AUC, area under curve; CCC, concordance correlation coefficient; CI, confidence interval; COS, COSMED data; HR, heart rate; LoA, limits of agreement;  $r$ , Pearson's  $r$ ; RR, respiratory rate;  $\rho$ , Spearman's rho; VIT, VITALPATCH data;  $\tau$ , Kendall's tau.

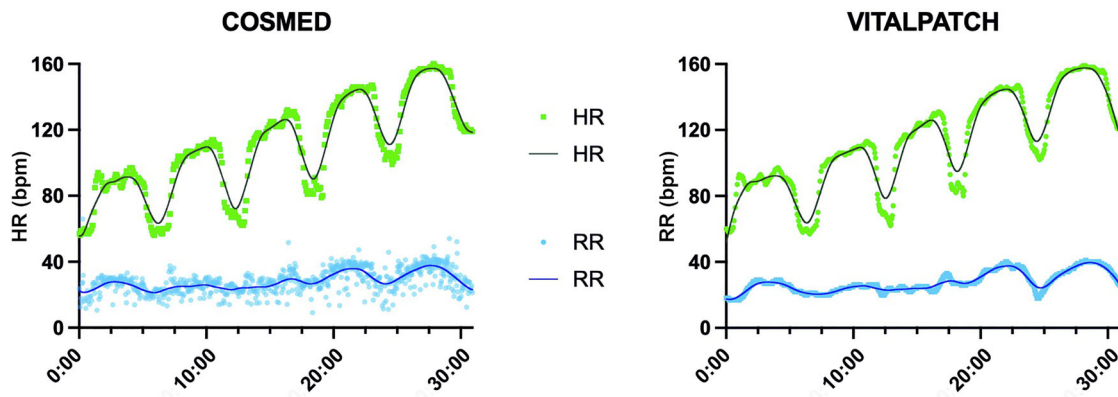
The full code is provided as [Supporting information](#).

## 3 | RESULTS

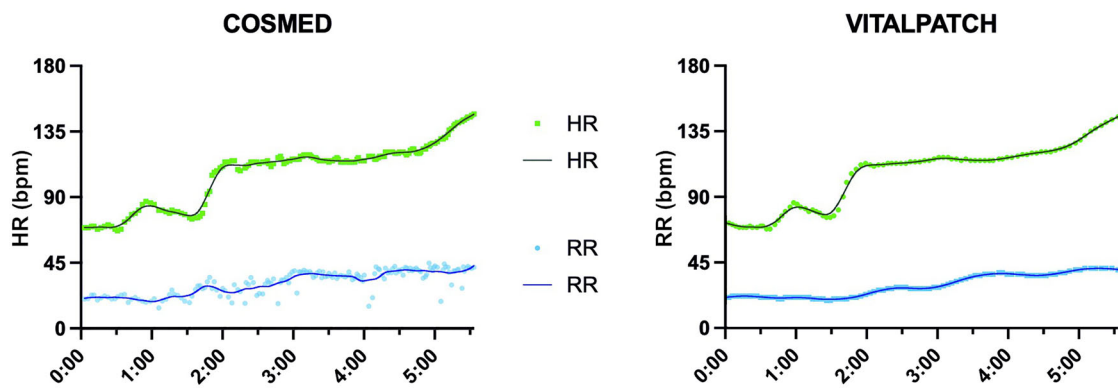
### 3.1 | Case report

The strength of agreement (McBride, 2005) across methods was considered substantial for HR and poor (although very close to moderate) for RR in the incremental normoxic test; the AUC of curves filtered from VITALPATCH data was 2.40% greater and 0.93% lower for HR and RR, respectively (Figure 1 and Table 1). A previous validation of VITALPATCH data to HR derived from three-lead ECG and RR determined from capnography measurements (Areia et al., 2021) revealed HR to have a mean bias of 0.31 (95% LoA –3.80 to 4.42) bpm, a precision (Pearson's  $r$ ) of 0.995 during rest, a mean bias of 1.92 (95% LoA –8.75 to 12.59) bpm and a precision of 0.975 during the sit-to-stand task, while RR had a mean bias of –1.94 (95% LoA –6.68 to 2.79) bpm, a precision of 0.849 during rest, a mean bias of 1.59 (95% LoA –10.7 to 7.53) bpm and a precision of 0.748 during the sit-to-stand task.

The strength of agreement (McBride, 2005) across methods was considered almost perfect for HR and moderate for RR in the TTE hypoxic test; the AUC of curves filtered from VITALPATCH data was 0.30% greater and 3.78% lower for HR and RR, respectively (Figure 2 and Table 2). A previous validation of VITALPATCH data to HR derived from a three-lead ECG and RR determined from capnography measurements (Areia et al., 2021) revealed HR to have a mean bias of 0.49 (95% LoA –1.58 to 2.56) bpm and a precision (Pearson's  $r$ ) of



**FIGURE 1** Comparison of data registered with COSMED and VITALPATCH devices during the incremental test in normoxia. Scatter points represent raw data, and the fine smoothing lines were obtained by running a LOWESS method. Data included several 4-min bouts with 2 min of rest between each bout.



**FIGURE 2** Comparison of data registered with COSMED and VITALPATCH devices during the time-to-exhaustion test in hypoxia. Scatter points represent raw data, and the fine smoothing lines were obtained by running a LOWESS method. Data included the warm-up followed by the workload.

approximately 1 during hypoxia exposure with participants gradually desaturating down to 80%  $S_{pO_2}$ , while RR had a mean bias of  $-0.08$  (95% LoA  $-5.80$  to  $5.65$ ) bpm and a precision of  $0.849$ .

From ECG inter-day comparisons, we noticed that on some days (16 April, 14 June and 15 June) summary data of ECG intervals (Tables 3 and 4) lacked full plausibility. The days on which the volunteer performed comparable activities with data acquisition without too many missing points were the day of the normoxia test and the following day. A comparison of the ECG data and the HRV indices before and after the expedition revealed no clear differences, with heterogeneity of trends between the indices and some data almost overlapping. Furthermore, clear trends in the indices on the days following the tests could not be demonstrated, which was also due to differences in the activities carried out on those days.

Atypical episodes included synus bradycardia, synus tachycardia, ventricular ectopies, supraventricular ectopies, supraventricular tachycardia, supraventricular tachyarrhythmia and atrial fibrillation. A lot of synus bradycardia episodes occurred, although those were related to the low resting HR of the subject and were not considered.

The other alerts were considered false or highly uncertain, possibly due to electrical noise and movement artifacts (see example in Figure 3), and the physicians suggested verifying the status with a clinical setting. However, the physicians confirmed atrial bigeminies (Figure 4) that appeared only after the expedition on the day between normoxic and hypoxic tests to be true.

During the night, both before and after the expedition, we observed 1–3 events per hour of nocturnal peaks in heart rate (see examples in Figure 5). These episodes may be due to nocturnal movements or apnoeic episodes, and ECG-reading were furtherly explored by clinicians.

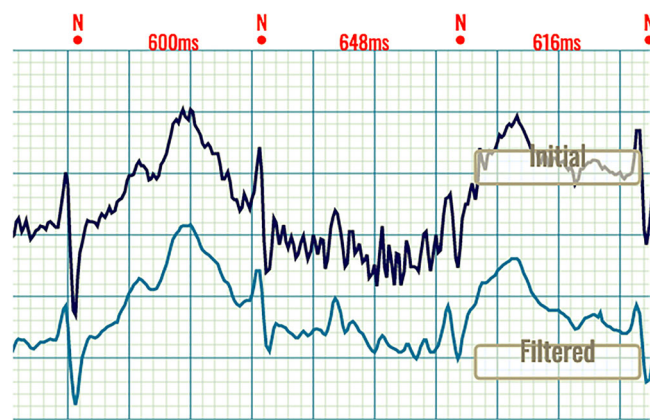
### 3.2 | Case series

Tables 5 and 6 report the analytical values. The strength of agreement across methods was considered substantial for HR and poor for RR; the AUC of curves filtered from VITALPATCH compared to COSMED remained under 3% of difference, while a large discrepancy emerged

**TABLE 2** Comparison of data registered from COSMED and VITALPATCH devices during the hypoxic test, after the expedition.

|             |                  | HR            | RR            |
|-------------|------------------|---------------|---------------|
| Bias        | Mean (COS – VIT) | –0.3215       | 1.151         |
|             | 95% LoA          | –4.767, 4.124 | –4.884, 7.186 |
| AUC         | COS              | 35,171        | 10,132        |
|             | VIT              | 35,278        | 9749          |
| Precision   | $r$              | 0.994         | 0.916         |
|             | $\rho$           | 0.991         | 0.860         |
|             | $\tau$           | 0.931         | 0.638         |
| Scale shift | $\omega$         | 1.005         | 1.020         |
| Effect size | $\nu$            | 0.015         | 0.153         |
| Accuracy    | $\chi_a$         | >0.999        | 0.988         |
| Lin's CCC   | $\rho_c$         | 0.994         | 0.905         |
|             | 95% CI           | 0.994, 0.995  | 0.900, 0.911  |

All correlation measures were statistically significant with  $P < 0.001$ . Abbreviations: AUC, area under curve; CCC, concordance correlation coefficient; CI, confidence interval; COS, COSMED data; HR, heart rate; LoA, limits of agreement;  $r$ , Pearson's  $r$ ; RR, respiratory rate;  $\rho$ , Spearman's rho; VIT, VITALPATCH data;  $\tau$ , Kendall's tau.

**FIGURE 3** Example of artifacts. Graph was retrieved from the online platform associated with the VITALPATCH device, that is <https://csptelemecinecv.web.app>.

concerning RR, with VITALPATCH underestimating values. Overall, greater differences emerged during the TTE test, rather than during the incremental test. From graphs shown in Figures 6, 7, 8, and 9 one can observe the difference areas (highlighted in grey) between COSMED and VITALPATCH filtered data.

It should be observed that RR signals obtained from VITALPATCH appear to be considerably smoother than RR signals from COSMED, despite the common filtering algorithm used for both series, thus resulting in poor overall concordance. Therefore, reporting spot values for a given moment from VITALPATCH should not be considered valid. However, the trend of values is almost superimposable, and mean bias was overall acceptable, except for one incremental and one TTE test in the hypoxic condition.

From ECG reports, several alarms were notified (Table 7). However, they were considered false or highly uncertain by the physicians, possibly due to electrical noise and movement artifacts. The report of clinical ECG conducted during the test is shown in Table 8. The physicians highlighted that some events of false paroxysmal supra-ventricular tachycardia emerged due to artifacts. Altered rhythmic patterns registered during the test for participants ID1 and ID3 (see Table 7) also emerged from 24-h registration of the VITALPATCH-registered bipolar ECG. Except for participant ID1, the values of multi-day ECG and multi-day HRV reports are plausible.

During the nights, as previously shown with regards to case report's example night strip, on average 1–3 events per hour of nocturnal peaks in heart rate were noticed.

## 4 | DISCUSSION

Within the growing field of sensorized patches, the VITALPATCH biosensor previously achieved acceptable accuracies for heart rate, RR and skin temperature in bench testing and in the stationary period (Selvaraj et al., 2018). This study aimed to provide preliminary data on either usefulness or warning for using VITALPATCH in a hypoxic environment.

Compared to a previous validation under hypoxic conditions (Areia et al., 2021), lower agreement was obtained for RR, particularly during the time-to-exhaustion test. Our tests were far more stressful than those of the previous validation, and a lot of motion artifacts emerged for the bipolar ECG, which biased the ECG-related events and the computation of RR. It should be noted that the breath-by-breath mode of the COSMED system allows the capture of breath-by-breath alterations of the ventilatory pattern, which is inherently not precisely and accurately allowed in the VITALPATCH system.

The possibility of analysing the RR trend (at least up to 42 bpm) still allows the use of VITALPATCH to monitor this vital sign during low- and medium-intensity activity at high altitude. However, this inherent limitation restricts the application of VITALPATCH monitoring during high-intensity exercise; this limitation becomes even more apparent under hypoxic conditions, where the RR is generally higher in hypoxia compared to normoxia for any given exercise intensity, although this effect exhibits inter-individual heterogeneity (Bondi & Verratti, 2023; Fornasiero et al., 2019). Heart rate monitoring proves to be valuable, but high body movements lead to motion artifacts on the ECG signal and thus on the reconstruction of HR and in the report of alarms. Considering sleep as a predominantly stationary phase and as highly susceptible to hypoxia, the use of VITALPATCH for sleep monitoring, given the comfort of this biosensor, is of considerable perspective.

The online platform associated with the VITALPATCH device in our experience was useful for real-data monitoring and data processing. The possibility of obtaining raw data from wearable/portable devices should become a recommendation, since it allows the development of customized analysis and modelling for comparing continuous vital signs from different devices, as we did for this project and released as Supporting information.

**TABLE 3** ECG-derived metrics from VITALPATCH data before the expedition.

|                    |                            | 16 April           | 17 April           | 18 April           | 19 April           | 20 April           |
|--------------------|----------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
|                    | Duration                   | 06:14:22           | 11:19:36           | 17:24:43           | 11:19:50           | 13:33:47           |
|                    | <i>n</i> beats             | 22,422             | 36,022             | 55,419             | 39,242             | 43,625             |
|                    | Mean HR (bpm)              | 62                 | 55                 | 54                 | 59                 | 55                 |
| ECG shape          | Mean QRS (ms)              | 77                 | 95                 | 102                | 106                | 109                |
|                    | Mean QT <sub>c</sub> (ms)  | 273                | 333                | 352                | 364                | 366                |
|                    | Mean PR (ms)               | 78                 | 130                | 156                | 163                | 169                |
| HRV metrics        | SDNN (ms)                  | 164                | 263                | 180                | 186                | 250                |
|                    | RMSSD (ms)                 | 61                 | 60                 | 61                 | 57                 | 73                 |
|                    | pNN50                      | 31%                | 34%                | 38%                | 31%                | 41%                |
|                    | LF peak (ms <sup>2</sup> ) | 2721<br>(0.066 Hz) | 2756<br>(0.097 Hz) | 1556<br>(0.059 Hz) | 2224<br>(0.056 Hz) | 2951<br>(0.066 Hz) |
|                    | HF peak (ms <sup>2</sup> ) | 770<br>(0.244 Hz)  | 357<br>(0.297 Hz)  | 841<br>(0.314 Hz)  | 812<br>(0.347 Hz)  | 746<br>(0.255 Hz)  |
|                    | LF/HF                      | 3.57               | 7.72               | 1.85               | 2.74               | 3.96               |
|                    | DFA <sub>α1</sub>          | 1.13               | 1.17               | 0.85               | 0.91               | 1.00               |
|                    | DFA <sub>α2</sub>          | 1.05               | 0.79               | 1.14               | 1.01               | 0.84               |
| Atypical beat type | PAC                        | 5                  | 1                  | 7                  | 0                  | 6                  |
|                    | PVC                        | 0                  | 0                  | 1                  | 0                  | 0                  |
|                    | AB                         | 0                  | 0                  | 0                  | 0                  | 0                  |

Abbreviations: AB, atrial bigeminy; DFA, detrended fluctuation analysis; HR, heart rate; LF, low-frequency band; HF, high-frequency band; PAC, premature atrial contractions; pNN50, percentage of successive RR intervals that differ by more than 50 ms; PVC, premature ventricular contractions; RMSSD, root mean square of successive RR interval differences; SDNN, standard deviation of NN intervals.

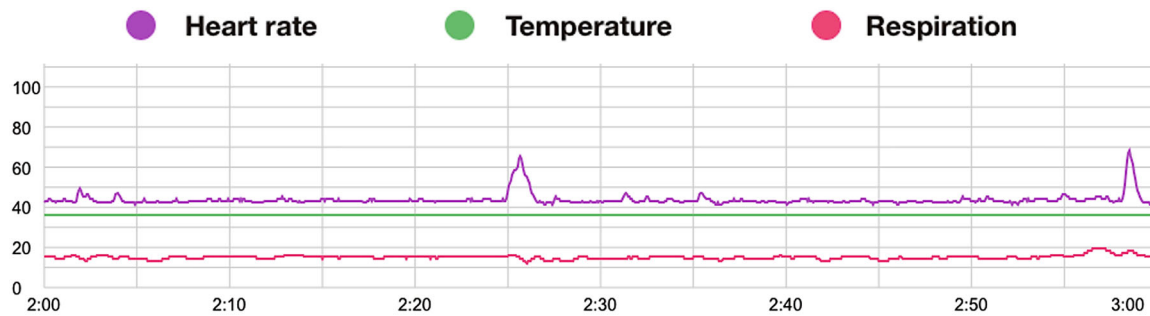
**TABLE 4** ECG-derived metrics from VITALPATCH data after the expedition.

|                    |                            | 10 June           | 11 June            | 12 June            | 13 June            | 14 June            | 15 June            |
|--------------------|----------------------------|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
|                    | Duration                   | 07:42:09          | 19:45:42           | 16:54:46           | 13:16:19           | 07:19:23           | 10:17:04           |
|                    | <i>n</i> beats             | 30,867            | 63,680             | 57,156             | 42,318             | 25,730             | 35,411             |
|                    | Mean HR (bpm)              | 69                | 54                 | 57                 | 54                 | 60                 | 58                 |
| ECG shape          | Mean QRS (ms)              | 96                | 100                | 102                | 98                 | 42                 | 55                 |
|                    | Mean QT <sub>c</sub> (ms)  | 334               | 353                | 355                | 343                | 146                | 189                |
|                    | Mean PR (ms)               | 125               | 131                | 133                | 112                | 22                 | 38                 |
| HRV metrics        | SDNN (ms)                  | 198               | 190                | 286                | 222                | 164                | 221                |
|                    | RMSSD (ms)                 | 43                | 66                 | 62                 | 66                 | 55                 | 55                 |
|                    | pNN50                      | 17%               | 41%                | 34%                | 39%                | 30%                | 28%                |
|                    | LF peak (ms <sup>2</sup> ) | 946<br>(0.033 Hz) | 1303<br>(0.048 Hz) | 1947<br>(0.054 Hz) | 2290<br>(0.063 Hz) | 2579<br>(0.085 Hz) | 2702<br>(0.079 Hz) |
|                    | HF peak (ms <sup>2</sup> ) | 386<br>(0.288 Hz) | 929<br>(0.284 Hz)  | 882<br>(0.307 Hz)  | 878<br>(0.375 Hz)  | 307<br>(0.349 Hz)  | 460<br>(0.280 Hz)  |
|                    | LF/HF                      | 2.45              | 1.40               | 2.21               | 2.61               | 8.39               | 5.87               |
|                    | DFA <sub>α1</sub>          | 1.19              | 0.64               | 0.55               | 1                  | 0.84               | 1.1                |
|                    | DFA <sub>α2</sub>          | 1.08              | 1.12               | 0.91               | -1.51              | 1.12               | 0.71               |
| Atypical beat type | PAC                        | 4                 | 29                 | 2                  | 2                  | 0                  | 2                  |
|                    | PVC                        | 6                 | 9                  | 3                  | 0                  | 12                 | 0                  |
|                    | AB                         | 0                 | 5                  | 0                  | 0                  | 0                  | 1                  |

Abbreviations: AB, atrial bigeminy; DFA, detrended fluctuation analysis; HR, heart rate; LF, low-frequency band; HF, high-frequency band; PAC, premature atrial contractions; pNN50, percentage of successive RR intervals that differ by more than 50 ms; PVC, premature ventricular contractions; RMSSD, root mean square of successive RR interval differences; SDNN, standard deviation of NN intervals.



**FIGURE 4** Strip of atrial bigeminy. Graph was retrieved from the online platform associated with the VITALPATCH device, that is <https://csptelemecinecv.web.app>.



**FIGURE 5** Strip of nocturnal registration with HR peaks. Graph was adapted from the online platform associated with the VITALPATCH device, that is <https://csptelemecinecv.web.app>.

**TABLE 5** Comparison of heart rate data registered from COSMED and VITALPATCH devices.

| Heart rate |             |    |                   |       |                        |        | Spearman's correlation |  |
|------------|-------------|----|-------------------|-------|------------------------|--------|------------------------|--|
| Condition  | Test        | ID | AUC (% $\Delta$ ) | CCC   | Mean bias (LoA) (bpm)  | $\rho$ | <i>P</i>               |  |
| Normoxia   | Incremental | 1  | +0.41             | 0.952 | +0.43 (−10.12, +10.98) | 0.942  | <0.001                 |  |
|            |             | 3  | +1.16             | 0.972 | +1.32 (−6.86, +9.49)   | 0.983  | <0.001                 |  |
|            | TTE         | 4  | +0.16             | 0.995 | −0.19 (−3.67, +4.05)   | 0.994  | <0.001                 |  |
|            |             | 3  | −1.47             | 0.985 | −1.70 (−7.11, +3.71)   | 0.951  | <0.001                 |  |
| Hypoxia    | Incremental | 4  | −0.30             | 0.992 | −0.36 (−4.93, +4.20)   | 0.989  | <0.001                 |  |
|            |             | 2  | +0.57             | 0.989 | +0.51 (−4.96, +5.98)   | 0.989  | <0.001                 |  |
|            | TTE         | 3  | +2.55             | 0.913 | +2.64 (−10.70, +16.00) | 0.951  | <0.001                 |  |
|            |             | 2  | +2.93             | 0.942 | +2.87 (−8.43; +14.17)  | 0.918  | <0.001                 |  |

Abbreviations: AUC, area under the curve; CCC, Lin's concordance correlation coefficient; LoA, limits of agreement; TTE, time to exhaustion.

#### 4.1 | Limitations and troubleshooting

Firstly, the design of this study, which involved a limited number of participants and signals, does not permit the provision of definitive conclusions regarding the validity of data acquired during exercise in hypoxia from the VITALPATCH device in comparison to those obtained from the COSMED device. Consequently, a cautious approach should

be adopted when interpreting the results. A further limitation pertains to the simulated altitude (approximately 5000 m), which constituted a solitary hypoxic condition and extended well beyond the reported operational range of VITALPATCH.

A limit for the use of VITALPATCH during field studies is the presence of motion artifacts. Artifacts resulted in low data quality, over-reported events, and possible inaccuracy in electrocardiogram-

**TABLE 6** Comparison of respiratory rate data registered from COSMED and VITALPATCH devices.

| Respiratory rate |             |    |          |       |                        | Spearman's correlation |        |
|------------------|-------------|----|----------|-------|------------------------|------------------------|--------|
| Condition        | Test        | ID | AUC (%Δ) | CCC   | Mean bias (LoA) (bpm)  | $\rho$                 | P      |
| Normoxia         | Incremental | 1  | +2.13    | 0.531 | +0.35 (−4.43; +5.13)   | 0.589                  | <0.001 |
|                  |             | 3  | −1.68    | 0.439 | −0.40 (−7.62; +6.82)   | 0.497                  | <0.001 |
|                  |             | 4  | 0.00     | 0.495 | 0.00 (−5.09; +5.09)    | 0.509                  | <0.001 |
|                  | TTE         | 3  | −5.09    | 0.592 | −1.14 (−7.73; +5.44)   | 0.713                  | <0.001 |
|                  |             | 4  | −0.19    | 0.362 | −0.04 (−4.50; +4.42)   | 0.409                  | <0.001 |
|                  |             |    |          |       |                        |                        |        |
| Hypoxia          | Incremental | 2  | −14.53   | 0.359 | −3.89 (−20.01; +12.24) | 0.486                  | <0.001 |
|                  |             | 3  | −3.52    | 0.675 | −0.74 (−8.60; +7.11)   | 0.622                  | <0.001 |
|                  | TTE         | 2  | −20.92   | 0.397 | −5.63 (−26.18; +14.91) | 0.696                  | <0.001 |

Abbreviations: AUC, area under the curve; CCC, Lin's concordance correlation coefficient; LoA, limits of agreement; TTE, time to exhaustion.

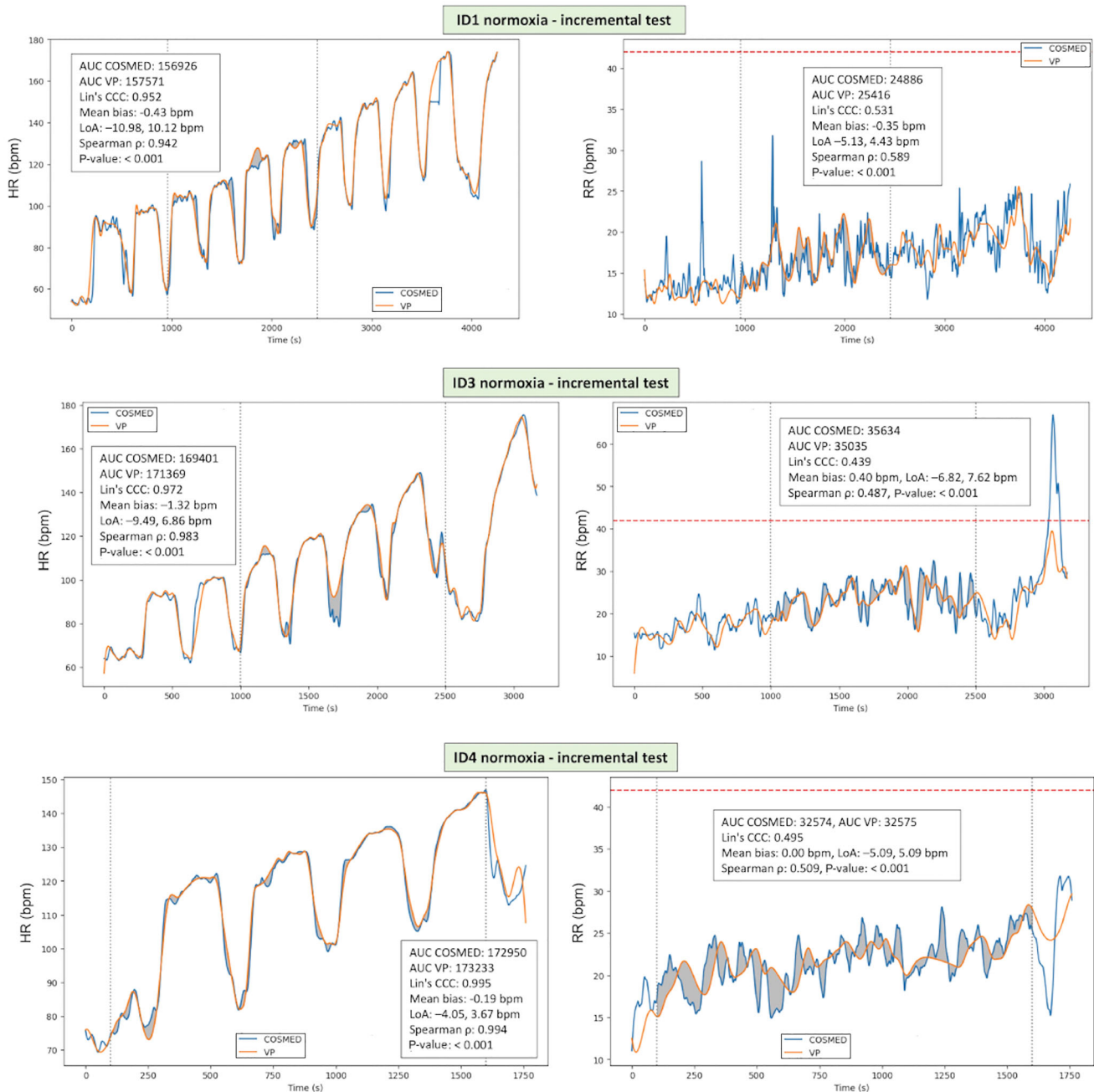
**TABLE 7** ECG-derived metrics from VITALPATCH.

|     | Normoxia   |   | Hypoxia  |                          |
|-----|--|---|--|--------------------------|
|     | Incremental  | TTE   | Incremental  | TTE                      |
| ID1 | 1 AF<br>8 SVTA<br>73 SVT<br><br>Multi-day ECG: mean QRS = 11 ms; mean QT <sub>c</sub> = 51 ms<br>Multi-day HRV: RMSSD = 142 ms; LF/HF = 0.76 | No data   | No data  | No data                  |
| ID2 | No data  | No data   | 4 SVTA<br>6 VT<br>6 SVT<br><br>Multi-day ECG: mean QRS = 81 ms; mean QT <sub>c</sub> = 311 ms<br>Multi-day HRV: RMSSD = 111 ms; LF/HF = 2.01 | 1 SVTA<br>3 VT<br>13 SVT |
| ID3 | 18 SVT   | 3 SVT   | 1 VB<br>6 VT<br>16 SVT<br><br>Multi-day ECG: mean QRS = 82 ms; mean QT <sub>c</sub> = 377 ms<br>Multi-day HRV: RMSSD = 51 ms; LF/HF = 1.5    | No data                  |
| ID4 | 2 SVTA<br>21 SVT   | 1 VB<br>2 SVTA<br>5 VT<br>39 SVT<br><br>Multi-day ECG: mean QRS = 102 ms; mean QT <sub>c</sub> = 390 ms<br>Multi-day HRV: RMSSD = 77 ms; LF/HF = 1.55 | No data  | No data                  |

Abbreviations: AF, atrial fibrillation; SVT, supraventricular tachycardia; SVTA, supraventricular tachyarrhythmia; TTE, time-to-exhaustion; VB, ventricular bigeminy; VT, ventricular tachycardia.

derived respiration (EDR). This problem was indeed present in other projects, for example, for computing EDR from a bipolar ECG signal registered from a chest strap (Sbrollini et al., 2022). Artifacts were presumed to be present, given the relative movement of the skin on the underlying tissue, and the presence of clothing that may further create mechanical stimuli on the sensor. The sensor was developed for the purpose of remote monitoring of patients under conditions of near-absent or otherwise poor motion. It is therefore presumed that its validity in our setting is reduced. It is recommended that future

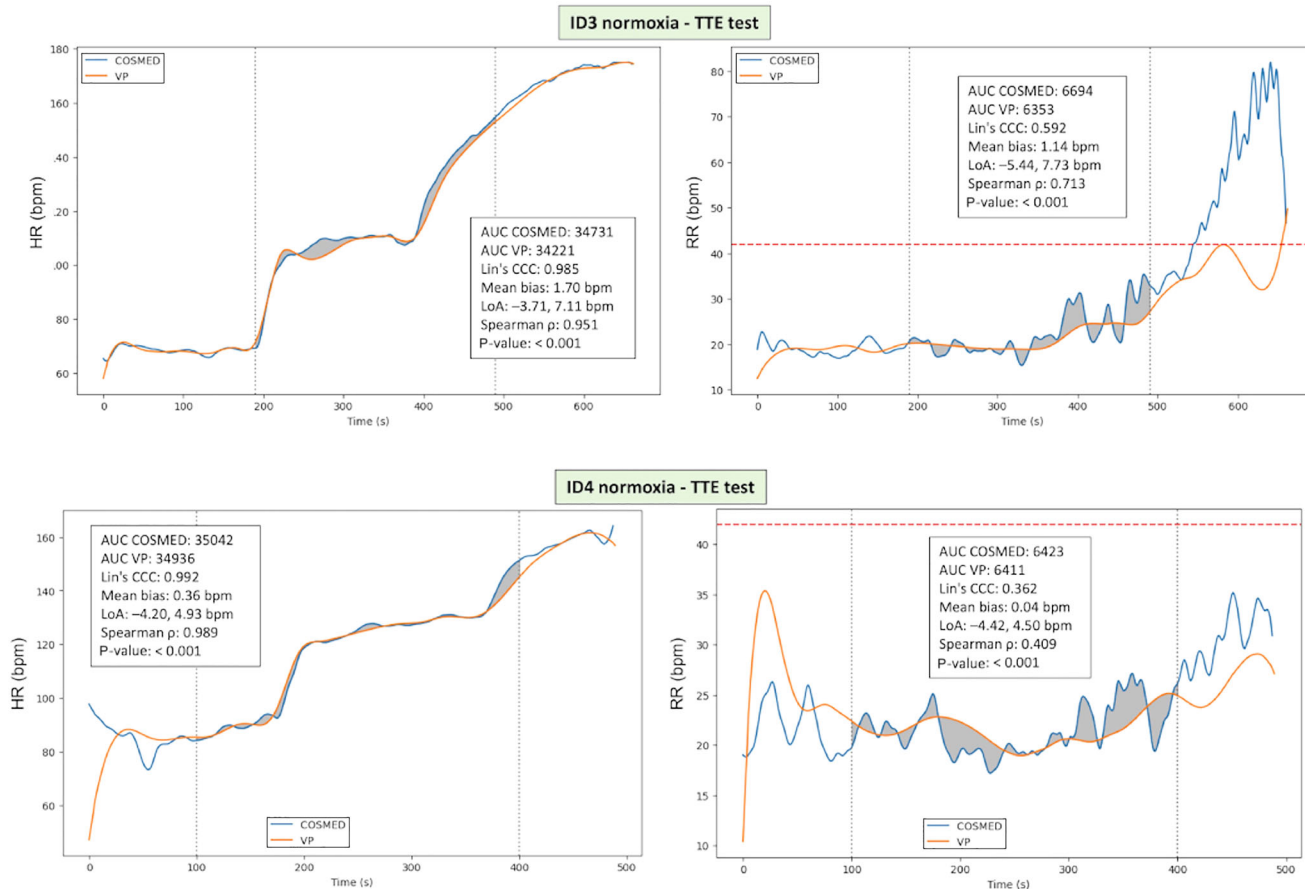
developments in this regard include the implementation of robust filtering algorithms that can either deal with acceptable artifacts or exclude all those time windows in which the recording is unreliable. Another major limit is the maximum value of 42 breaths/min, a limit that as above refers to the use for which the sensor was developed, under conditions where values considerably lower than this threshold are recorded. Moreover, VITALPATCH does not capture  $S_{pO_2}$ , which is of interest during high-altitude exposure, but it can be coupled to a third sensor.



**FIGURE 6** Comparison of heart rate (HR) and respiratory rate (RR) data from VITALPATCH (VP) and COSMED during the incremental test in normoxia. Analytical and statistical values are reported. Vertical lines denote the beginning and the end of the time window considered for the analyses. Horizontal lines in right panels denotes the maximum threshold that the VITALPATCH system applied for RR. Grey area denotes the difference area from the two filtered lines. Calculation and graphs were created with Python.

The comparison of breathing pattern in challenging breathing conditions was biased, as COSMED was set to assess breath-by-breath metrics. The smoothing algorithms were set to maintain the fundamental ventilatory pattern, as an excessive smoothing leads to a lack of information that affects analyses aimed at assessing transfer of information and causality relationships from one physiological system to another, the core of network physiology (Bartsch et al., 2015) and which is of interest in hypoxia (Jiang et al., 2021).

The use of recumbent cycling was determined within a broader experimental design, in which multiple physiological measurements were performed simultaneously during exercise. The recumbent cycling modality offers advantages in terms of upper-body stability and reduced movement artifacts, which is particularly relevant when assessing respiratory parameters with wearable or sensor-based instruments. This set-up allowed us to obtain more controlled and reliable measurements under steady conditions. However, different



**FIGURE 7** Comparison of heart rate (HR) and respiratory rate (RR) data from VITALPATCH (VP) and COSMED during the time-to-exhaustion test in normoxia. Analytical and statistical values are reported. Vertical lines denote the beginning and the end of the time window considered for the analyses. Horizontal lines in right panels denotes the maximum threshold that the VITALPATCH system applied for RR. Grey area denotes the difference area from the two filtered lines. Calculation and graphs were created with Python.

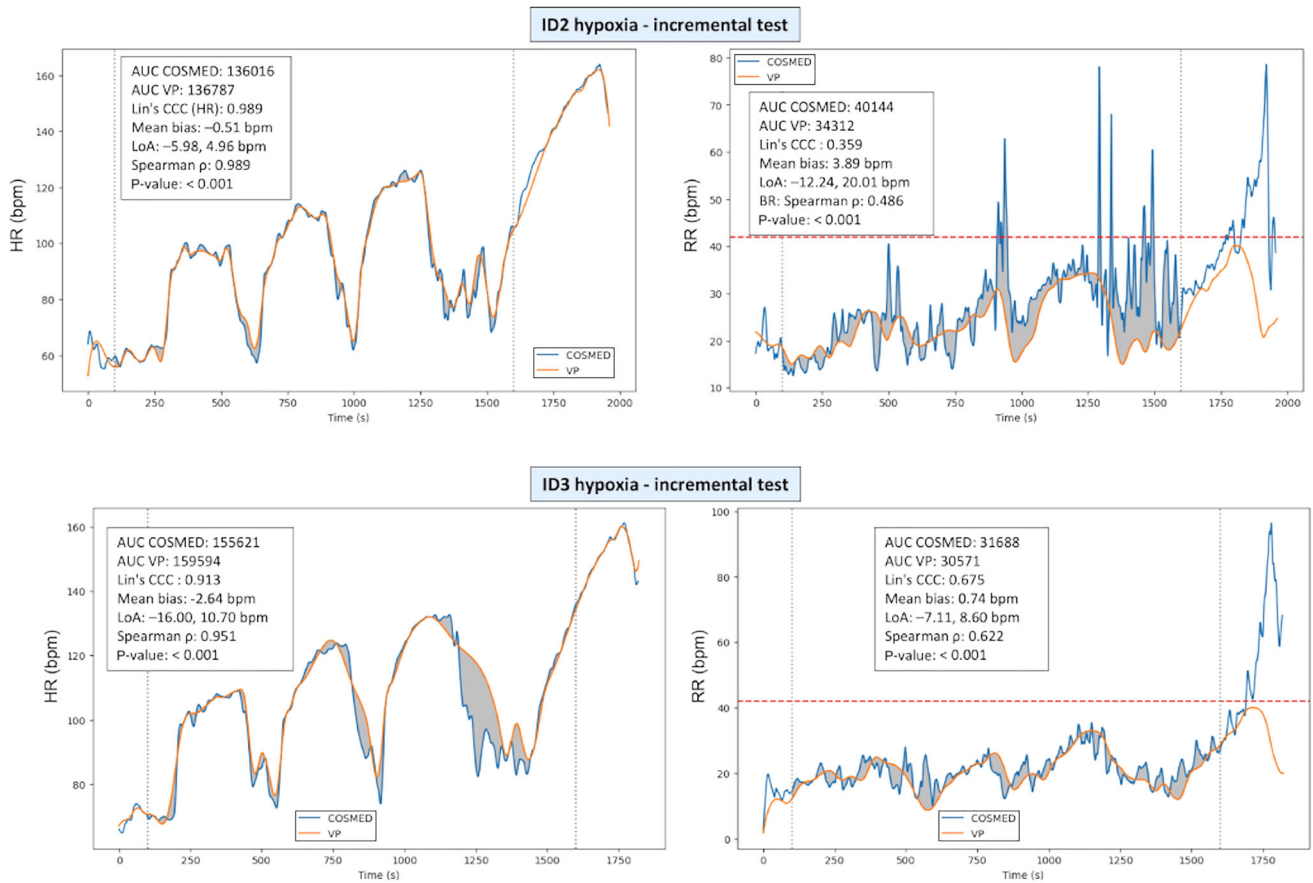
**TABLE 8** ECG clinic reports during the tests.

|     | Normoxia                      |                                     | Hypoxia   |                                |
|-----|-------------------------------|-------------------------------------|---|--------------------------------|
|     | Incremental                   | TTE                                 | Incremental   | TTE                            |
| ID1 | 2 VEBs<br>Data quality: fair  | 9 VEBs<br>Data quality: low         | Pronounced SA<br>8 VEBs, 1 SVEB<br>Data quality: fair | NA                             |
| ID2 | NA                            | NA                                  | No event;<br>Data quality:<br>optimal                 | NA                             |
| ID3 | NA                            | NA                                  | 1 VEB<br>Data quality: fair                           | No event<br>Data quality: fair |
| ID4 | 7 SVEBs<br>Data quality: fair | 3 SVEBs<br>Data quality:<br>optimal | Lots of artifacts<br>Data quality: low                | No event<br>Data quality: fair |

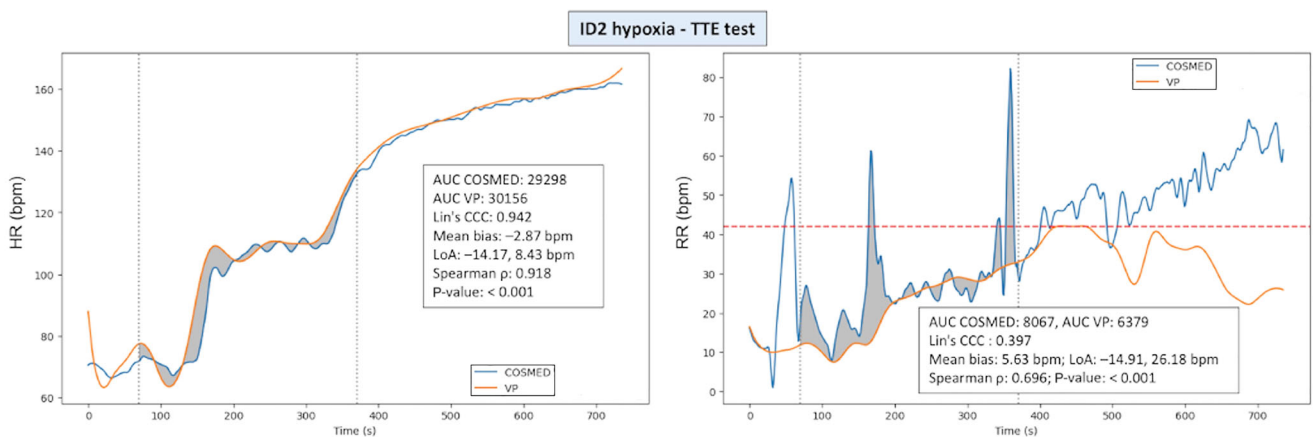
Abbreviations: NA, not available; SA, sinus arrhythmia; SVEB, supraventricular ectopic beat; VEB, ventricular ectopic beat.

exercise modalities may introduce additional sources of variability, particularly due to increased body movement and changes in breathing patterns. Therefore, future studies should specifically investigate the

performance of the instrument across different types of exercise to determine its robustness and validity in more dynamic and ecologically valid conditions.



**FIGURE 8** Comparison of heart rate (HR) and respiratory rate (RR) data from VITALPATCH (VP) and COSMED during the incremental test in hypoxia. Analytical and statistical values are reported. Vertical lines denote the beginning and the end of the time window considered for the analyses. Horizontal lines in right panels denotes the maximum threshold that VITALPATCH system applied for RR. Grey area denotes the difference area from the two filtered lines. Calculation and graphs were created with Python.



**FIGURE 9** Comparison of heart rate (HR) and respiratory rate (RR) data from VITALPATCH (VP) and COSMED during the time-to-exhaustion test in hypoxia. Analytical and statistical values are reported. Vertical lines denote the beginning and the end of the time window considered for the analyses. Horizontal lines in right panels denotes the maximum threshold that VITALPATCH system applied for RR. Grey area denotes the difference area from the two filtered lines. Calculation and graphs were created with Python.

## 4.2 | Perspectives and conclusions

Body patches would be of great usefulness in physiological monitoring at high altitude, as these biosensors reduce challenges of wearable sensors in extreme environments such as extreme cold exposure. In consideration of the potential application of the VITALPATCH sensor in high-altitude field studies for remote monitoring, the following conclusions can be drawn, although general caution is required given the small size of the sample:

- Hypoxia per se does not affect the quality of the recording.
- The integrity of the recording for reporting ECG events is significantly compromised by the presence of artefacts, which usually lead to over-reporting; the implementation of novel pre-processing filtering algorithms has the potential to enhance the reliability of the data.
- The process of heart rate monitoring is superimposable on that of a chest strap.
- Spot values, as well as minimum, maximum and mean values, from RR monitoring are unreliable in circumstances necessitating modified breathing patterns (e.g., maximal exertion where breath is occasionally held) or conditions where RRs approaching 42 bpm are attained; the employment of novel algorithms for EDR, incorporating conservative filtering to eliminate unreliable windows, has the potential to enhance data reliability.
- In resting conditions and in those efforts which are submaximal and not greatly pulsatile, both heart rate and respiration rate monitoring have been shown to be reliable and informative; this lends weight to the use for monitoring sleep.
- Although the features of VITALPATCH do not allow the capture of breath-by-breath ventilatory patterns, the overall trend can allow the use of RR for network physiology approaches.
- Given the reliability criteria are met, the possibility of automatically obtaining 24-h ECG data of clinically relevant intervals (such as QT) and a HRV comprehensive report are useful features.
- Temperature and motion monitoring, which were not the focus of the present study, remain a useful opportunity for expeditions in extreme environments.
- The device in its current form is not suitable for mountain rescue.

The following section outlines a potential workflow to optimize the use of VITALPATCH during high altitude studies:

- ensuring that recent stress ECGs are obtained for each subject, accompanied by a clinical report;
- structuring of a pre-test, conducted by using validated tools for the monitoring of cardiac and respiratory response during rest and incremental testing, so as to create reliable references for comparison;
- prior to application of the sensor, skin must be meticulously cleansed and shaved to ensure optimal adhesion, and the utilization of the

additional cover is recommended to enhance the adhesion of the patch to the chest;

- regular monitoring of the data from the online platform in order to ascertain the plausibility of the recordings and to ascertain the battery levels, which permit approximately 7 days of recording;
- being mindful of the fact that the platform is prone to reporting erroneous data when RRs exceed 42 beats/min;
- during movement, relying on data trend for RR, rather than on spot values
- consulting a cardiology specialist in order to verify the functionality of the alarms;
- creating 24-h or multi-day reports for ECG and HRV;
- downloading the raw data of a selected time period, an option which is always available from the associated platform, with a view to developing independent filtering and analyses.

### AUTHOR CONTRIBUTIONS

Conceptualization: Danilo Bondi and Anna Pedrinolla. Methodology: Danilo Bondi and Anna Pedrinolla. Software: Danilo Bondi; Formal Analysis: Danilo Bondi and Anna Pedrinolla. Investigation: Ferdinando Calcagno, Elisa Fioraso, and Anna Pedrinolla. Validation: Danilo Bondi. Writing—Original Draft: Danilo Bondi and Anna Pedrinolla. Writing—Review & Editing: Ferdinando Calcagno, Elisa Fioraso, Camillo Di Giulio, and Federico Schena. Funding Acquisition: Anna Pedrinolla. Resources: Danilo Bondi, Camillo Di Giulio, Federico Schena, and Anna Pedrinolla. Data curation: Danilo Bondi and Anna Pedrinolla. Visualization: Danilo Bondi. Supervision: Camillo Di Giulio. Project Administration: Federico Schena and Anna Pedrinolla. All authors have read and approved the final version of this manuscript and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All persons designated as authors qualify for authorship, and all those who qualify for authorship are listed.

### ACKNOWLEDGEMENTS

Open access publishing facilitated by Università degli Studi Gabriele d'Annunzio Chieti Pescara, as part of the Wiley - CRUI-CARE agreement.

### CONFLICT OF INTEREST

None declared.

### DATA AVAILABILITY STATEMENT

Data will be available upon reasonable request.

### FUNDING INFORMATION

None.

### ORCID

Danilo Bondi  <https://orcid.org/0000-0003-1911-3606>

Ferdinando Calcagno  <https://orcid.org/0009-0006-1351-6382>

Camillo Di Giulio  <https://orcid.org/0000-0003-1073-6989>

## REFERENCES

- Areia, C. M., Santos, M., Vollam, S., Pimentel, M., Young, L., Roman, C., Ede, J., Piper, P., King, E., Gustafson, O., Harford, M., Shah, A., Tarassenko, L., & Watkinson, P. (2021). A chest patch for continuous vital sign monitoring: Clinical validation study during movement and controlled hypoxia. *Journal of Medical Internet Research*, *23*(9), e27547.
- Bartsch, R. P., Liu, K. K. L., Bashan, A., & PCh, I. (2015). Network physiology: How organ systems dynamically interact. *PLoS ONE*, *10*(11), e0142143.
- Bondi, D., & Verratti, V. (2023). Respiration in extreme environments. In L. Burattini, V. Camomilla, & M. Knaflitz, (Eds.), *The bioengineering of sport*. (pp. 255–267). Patron.
- Chen, J., Tian, Y., Zhang, G., Cao, Z., Zhu, L., & Shi, D. (2023). IoT-enabled intelligent dynamic risk assessment of acute mountain sickness: The role of event-triggered signal processing. *IEEE Transactions on Industrial Informatics*, *19*(1), 730–738.
- Cobá Juárez Pegueros, J. P., & Rodríguez-Arce, J. (2025). Physiological datasets in stress and anxiety research: A systematic review. *Biomedical Signal Processing and Control*, *108*, 107928.
- Donavalli, S., Kambham, H., & Pitchaimanickam, B. (2024). Monitoring systems for mountain climbers using IoT. In *2024 10th International Conference on Communication and Signal Processing (ICCSP)*, (pp. 1315–1320). [Accessed June 9, 2025]. <https://ieeexplore.ieee.org/document/10544272>
- Fornasiero, A., Skafidas, S., Stella, F., Zignoli, A., Savoldelli, A., Rakobowchuk, M., Pellegrini, B., Schena, F., & Mourot, L. (2019). Cardiac autonomic and physiological responses to moderate-intensity exercise in hypoxia. *International Journal of Sports Medicine*, *40*(14), 886–896.
- Jiang, Y., Costello, J. T., Williams, T. B., Panyapiean, N., Bhogal, A. S., Tipton, M. J., Corbett, J., & Mani, A. R. (2021). A network physiology approach to oxygen saturation variability during normobaric hypoxia. *Experimental Physiology*, *106*(1), 151–159.
- Lin, L. I. (1989). A concordance correlation coefficient to evaluate reproducibility. *Biometrics*, *45*(1), 255–268.
- Liu, K., Tang, J., Jiang, Z., Wang, Y., Liu, X., Li, D., Li, D., & Shi, Y. (2024). Summit vitals: Multi-camera and multi-signal biosensing at high altitudes. In *2024 IEEE Smart World Congress (SWC)*, (pp. 284–291). [Accessed July 4, 2025]. <https://ieeexplore.ieee.org/document/10924930>
- Mali, A., Shah, N., & Patel, D. (2023). Patch sensor and wireless body area network for disease detection in human body: A comprehensive survey. *International Journal for Research in Applied Science & Engineering Technology*, *11*(VIII), IJRASET55467.
- McBride, G. B. (2005). A proposal for strength-of-agreement criteria for Lin's concordance correlation coefficient. <https://www.medcalc.org/download/pdf/McBride2005.pdf>
- Raymond, D. A., Kumar, P., & Goureshettiwar, P. (2024). Intergration of wearable biosensors and data analytics for remote health monitoring. In *2024 Second International Conference on Intelligent Cyber Physical Systems and Internet of Things (ICoCI)*, (pp. 707–713). [Accessed July 4, 2025]. <https://ieeexplore.ieee.org/document/10696310>
- Sbrollini, A., Bondi, D., Romagnoli, S., Morettini, M., Marcantoni, I., Pietrangelo, T., Verratti, V., & Burattini, L. (2022). Segmented-beat modulation method-based procedure for extraction of electrocardiogram-derived respiration from data acquired by wearable sensors during high-altitude activity. In *Computing in Cardiology*. [Accessed March 4, 2023]. <https://www.cinc.org/archives/2022/pdf/CinC2022-096.pdf>
- Selvaraj, N., Nallathambi, G., Moghadam, R., & Aga, A. (2018). Fully disposable wireless patch sensor for continuous remote patient monitoring. In *2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, (pp. 1632–1635). [Accessed July 4, 2025]. <https://ieeexplore.ieee.org/document/8512569>
- Shen, Y.-Y., Miller, J. T., & Anderson, A. P. (2020). Comfort, mobility, and durability assessment of a wearable IMU system for EVA suits. In *2020 IEEE Aerospace Conference*, (pp. 1–9). [Accessed July 4, 2025]. <https://ieeexplore.ieee.org/document/9172657>
- Thendral, R., Kavitha, C., & Abinathanan, A. (2024). Enhancing wellness and location monitoring for mountain climbers. In *2024 International Conference on Electronics, Computing, Communication and Control Technology (ICECCC)*, (pp. 1–6). [Accessed June 9, 2025]. <https://ieeexplore.ieee.org/document/10593915>

## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

**How to cite this article:** Bondi, D., Calcagno, F., Fioraso, E., Giulio, C. D., Schena, F., & Pedrinolla, A. (2026). Advancing tele-physiology: A chest patch solution for continuous, non-invasive remote monitoring in a hypoxic environment. *Experimental Physiology*, 1–14. <https://doi.org/10.1113/EP093718>