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# Innovative Smart Face Mask to Protect Workers from COVID-19 Infection

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***Abstract* - The most frequent prodromes of COVID-19 infection are fever and signs/symptoms of incipient respiratory diseases such as cough and shortness of breath or tachypnea. However, it is not infrequent that in patients infected with COVID-19, in addition to respiratory manifestations, cardiac rhythm alterations are also present which can be an early sign of an acute cardiovascular syndrome. It is therefore of utmost importance, especially for health care and civil protection workers who are most exposed to the infection, to detect the prodromal symptoms of this infection in order to be able to make a diagnosis of possible positivity to COVID-19 infection as quickly as possible and therefore to provide their immediate insertion in the isolation/therapy protocols. Here a prototype of a smart face mask is presented: the AG47-SmartMask. In addition to having the function of both an active and passive anti COVID-19 filter, the latter by an electro-heated filter brought to a minimum temperature of 38°C, the AG47-SmartMask also allows the continuous monitoring of numerous cardio-pulmonary variables. Several specific sensors are incorporated into the mask in an original way that assess the inside mask temperature, relative humidity and air pressure together with the auricular assessment of body temperature, heart rate and percentage of oxygen saturation of haemoglobin. Sensors work in synergy with an advanced telemedicine platform. To validate the device, twenty workers engaged in a vegetable packaging chain tested the tool simulating, while working, both tachypnea and cough, and the AG47-SmartMask faithfully quantified the simulated dyspnoic events**.

***Index Terms - COVID-19 infection, smart face mask, electro-heating active filtering, wearable biophysical sensors, telemedicine platform.***

## I. INTRODUCTION

Coronavirus disease 2019 (COVID-19) is a rapidly expanding global pandemic that causes severe acute respiratory syndrome (SARS-CoV-2), and could result in significant morbidity and even mortality. The most frequent prodromes of COVID-19 infection are fever and signs/symptoms of incipient respiratory diseases such as cough and shortness of breath or tachypnea [1]. However, it is not infrequent that in patients infected with COVID-19, in addition to respiratory manifestations, cardiac rhythm alterations are also present which can be the early sign of an acute cardiovascular syndrome (ACovCS) [2]. An almost obligatory consequence of all these occurrences is the concomitance of reduction in both lung ventilation and perfusion resulting in a breath by breath decrease of the exchange of gases between the alveoli and capillaries of the pulmonary circulation, with a decrease in the partial pressure of the oxygen physically dissolved in the arterial blood or an incomplete oxygen saturation of the hemoglobin. This gives rise to a tissue hypoxic hypoxia which is particularly critical especially for the central nervous and myocardial cells [3]. In fact, both these organs use almost entirely aerobic mechanisms, for which prolonged tissue hypoxia can give rise to irreversible structural damage with serious danger for the patient's life.

Fig. 1 The tridimensional image of the AG-47 SmartMask prototype is shown where the left filtering element, in the form of an interchangeable disk, is clearly visible together with the semi-rigid connection arm to the homologous ear in which some sensors are located

It is therefore of importance, especially for health care and civil protection workers who are most exposed to the infection, to detect the prodromal symptoms of this infection in order to be able to make a diagnosis of possible positivity to COVID-19 infection as quickly as possible and therefore to provide their immediate insertion in the isolation/therapy protocols. However, the risk of contracting the COVID-19 infection also occurs for workers in other production areas such as the workers on industrial production lines with mobile workstations that involve workers frequently approaching each other, and employees working in service companies whose workstations are closely spaced and located in open work spaces, the military operating in action groups that involve close individual proximity, etc. In all these workers, in addition to the frequent monitoring of body temperature, the continuous assessment of the breath-by-breath respiratory pattern and of the beat-to-beat heart rhythm together with the percentage of oxygen saturation in arterial blood, all in a non-invasive, wearable and remote way, can represent a medical choice of critical relevance. A recent study proposed a non-disposable, innovative self-disinfecting face mask, but without cardio-respiratory sensory implementation. However, these authors have not carried out any experimentation of their mask in workers engaged in the field [4].

Here a non-commercial prototype of a non-disposable smart face mask is presented, which, in addition to the function of an anti COVID-19 filter, also allows the continuous monitoring of numerous cardio-pulmonary variables by means of several specific sensors, incorporated into it in an original way, that work in synergy with an advanced telemedicine platform.

## II. METHODS

### A. *The face mask: material structure and design*

This wearable device is called the "AG-47 SmartMask" to highlight the silver used in its innovative filtering system (see figure 1). A key aspect of the AG-47 SmartMask is its droplet filtering functionality. In fact, its filters not only have class N95 filtering capacity (NB the N95 disposable mask standard appears to be the most widely used and therefore gives rise to highest level of non-ecologically sustainable waste), but they are also equipped with an advanced "active" filtration function, aimed at killing viruses in a permanent, autonomous and constant way, without accumulation or residues of infected organic deposits. The active filtration of the AG-47 is carried out by an electro-heated filter brought to a minimum temperature of 38°C. It is based on the thermolability principle presented by the SARS-CoV virus [5] which, with a good approximation, is comparable to the profile of the pathogen currently responsible for the pandemic in progress, as it belongs to the same family. The filtering action takes advantage of the action of the electric current passing through the filter, helping to reduce the viral load by producing a micro electrical discharge on the pathogen that deposits itself on the surface of the conducting silver wire constituting the active filter [6]. The AG-47 SmartMask can use the same filter for up to sixty days from first use; this face mask therefore does not belong to the category of "disposable" expiratory tract protection devices and therefore has an extremely limited environmental impact.

The so-called "active" action of the filter naturally adds to that of the "passive" type carried out by the non-woven fabric materials of which the common surgical masks are made. The dual "active-passive" functionality with which the filter of the AG-47 SmartMask is equipped is obtained by inserting a layer of a special, suitably spun conductive fabric (active filtering zone) between the two surface layers made of non-woven fabric materials (passive filtering zone). The active function of the mask is ensured by a low voltage power supply which must guarantee the maintenance of the thermal requirement established for a significant reduction of the viral load. At a temperature of 38°C and a relative humidity (RH) of 80-90% there is a significant decrease, up to 14 times, in the percentage of a standard infected culture dose (TCID50) over a period of time of 24h. A further increase in abatement, equal to 24.5 times, is obtained with 95% RH at 38°C, again in a time of 24h. Note how the RH values are almost similar to those of human breath and therefore replicable within the facial containment cavity of the respirator. Finally, SARS-CoV is completely eliminated at 56°C in 15 minutes [6]. This feature allows the entire filtering system of the AG-47 SmartMask to be automatically sanitized, without the need for any intervention by the user, simply by connecting the mask to an electrical transformer that delivers direct current at low voltage. The sanitization process, during which lithium-ion batteries that power the sensing and control electronics of the device are also recharged, is coordinated entirely by a Micro Controller Unit. This process is designed to be carried out, ideally, at the end of a prolonged session of use, such as a work shift (8h-10h, for example) and lasts about 15 minutes. At the end of the self-sanitization cycle, the AG-47 SmartMask can be reused in complete safety.

Fig. 2 Three-dimensional rendering of the AG-47 SmartMask with the positions of the main sensors highlighted in red. In the configuration shown, the mask is presented with a replication factor of 1 for the thermo-hygrobarometric (full red square) inside its facial containment cavity and with a replication factor of 2 for the intraural thermal sensors (red cones) and the pulsoximetry sensors for the ear lobe (black pliers)

### B. *The smart mask sensing apparata*

Figure 2 shows a three-dimensional rendering of the AG-47 SmartMask internal side where a configuration is visible that provides a minimum replication level equal to 1 as regards the thermo-hygro-barometric sensors present in the facial containment cavity of the mask but a level of replication higher, equal to 2, relative to intraural thermal sensors and pulse oximetry sensors for the ear lobe. The control electronics and the designs allow the use of 1, 3 or 5 thermo-hygro-barometric sensors inside the facial containment cavity of the mask in combination with one or two intraural thermal sensors and ear lobe pulse oximetry.

The dislocation of the thermo-hygrobarometric sensors under the internal surface of the facial containment chamber of the equipment in scenarios with 1, 3 or 5 different sensors was determined using computational fluid dynamics simulations, then also validated experimentally, thanks to which it was possible to identify the most suitable positions to capture the information necessary to accurately construct the environmental scenario present inside the mask during its use.

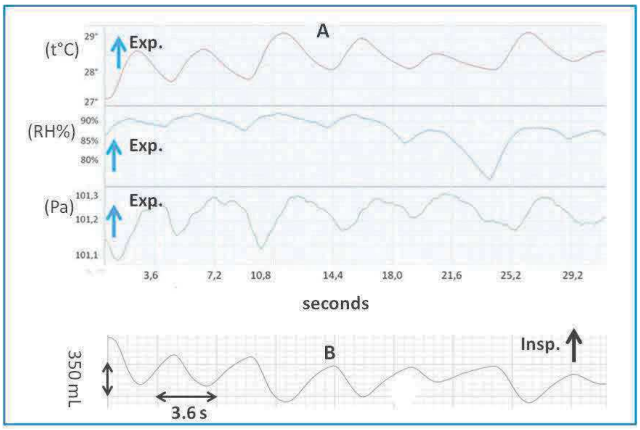

Fig. 3 Time trend of the electrical signals acquired, in A, respectively by the temperature (t°C), relative humidity (RH%) and pressure (Pa) sensors inside the AG-47 SmartMask during a sequence of 6 breaths in an asymptomatic subject at rest. In B, the spirographic trace acquired simultaneously by the same subject through strain gauges inserted in a belt applied around the chest and lying on the horizontal plane of the xiphoid process.

### *C. Thermo-hygro-barometric signals acquisition from inside the smart mask sensors*

With regard to the 6 quiet breaths of a healthy subject shown in the graphs of the figure 3A, from the time scale on the abscissa it can be deduced that the average duration of each breath was about 4 s, giving a respiratory rate of 15 breaths per minute. In the ordinate axes the temperature is measured in °C, the relative humidity in % of the maximum, the pressure in Pascal. The graph of figure 3B shows the trend of the tidal respiratory volume (the volume of air inhaled and exhaled for each quiet respiratory cycle, or the spirogram) obtained in the same subject by measuring the deformation of the chest with a device equipped with electronic strain gauges [7]. As shown by the orientation of the blue arrows on the left side in figure 3A, the temporal trend of the variations in these three physical quantities detected with the sensors inside the face mask is reciprocal with respect to that of the spirogram of figure 3B since their relative maximum values occur at the end of the exhalation while the minimum ones are observed at the end of inhalation. As shown in this figure, the path that morphologically, albeit reciprocally, best represents the reference spirometric one as regards the periodic trend of the tidal volume, is certainly the thermographic one. Furthermore, as shown by the instrumental traces detected from the AG-47 SmartMask on a healthy subject, the thermogram, hygrogram and barogram all have a sinusoidal-like oscillation whose duration interval is almost the same as that of the spirogram.

Thanks to the relative humidity sensor inserted inside the AG-47 SmartMask, it is possible to quantify the variations in the amount of water vapor that, during the expiratory phase, is introduced from the lungs into the space inside the mask. If the intra-mask partial pressure of this gas ($P_p$-$H_2O$) is higher than that of the external ambient air (the $P_p$-$H_2O$ in exhaled air is approximately 48 mmHg), a certain fraction of the vapor will filter out of the mask tending to balance the $P_p$-$H_2O$ of the mask with the external one until the expiratory phase ends and the inspiratory phase begins (during which, obviously, there is no introduction of water vapor from the lungs to the mask). However, the amplitude of this intra-mask $P_p$-$H_2O$ oscillation (which will have the maximum value at the end of expiration and the minimum at the end of inspiration) may show a tendency to decrease when the temperature and thus the $P_p$-$H_2O$ of the environment increase. This will continue until the two $P_p$-$H_2O$, respectively of the mask and of the environment, become equal, or when the $P_p$-$H_2O$ of the environment is also 48 mmHg which will correspond to an environmental microclimate temperature equal to 37°C.

In such an environmental condition, it is no longer possible to carry out heat exchanges between the body of the health care worker (entirely covered in waterproof anti-virus safety clothing) and the environment, so if appropriate action is not taken, the worker risks a condition of body hyperthermia which could lead to heat stroke, a condition of serious risk for his organs and systems. The specific importance of monitoring the $P_p$-$H_2O$ intra-mask oscillations is therefore evident, as a suitable variable to indicate the incipient risk of hyperthermic shock.

In the two phases of the respiratory cycle, the temperature of the air flow varies because the expiratory one, following the heating path in the conduction airways (bronchial tree, trachea, larynx and rhino-pharynx, mouth and basal turbinates) is warmer (around 32°C÷33°C) by a few degrees than the inspiratory one. Given the very limited volume of air contained in the space between the mask and facial skin, these thermal oscillations can also be acquired by the temperature sensors inside the mask and can therefore be used to determine the respiratory rate in a non-invasive way. However, the information contained in the data acquired by the temperature sensors also provides the absolute values of the temperature oscillations of this microenvironment which can be compared with those of the external environment. It could therefore appear that the amplitude of the oscillations of the intra-mask thermogram will progressively reduce as the external temperature increases but, despite the tendency to cancel itself out when the increasing external temperature reaches the internal average, the transport of thermal energy inside the mask in the two directions in and out from the lungs may still exist due to the thermal gradient that will remain for the convective motions in two opposite directions of the internal air.

However, the fact remains that even the progressive reduction in the amplitude of the oscillations of the thermogram, as well as those of the hygrogram previously described, signals the increased risk of hyperthermia for the healthcare worker.

From the pressure sensor installed inside the mask which detects the intra-face mask pressure oscillations (see the bottom instrumental trace of figure 3A), coughing can be detected and sized as excessive changes in the pressure of the expired air. Coughing is a respiratory event due to a particular system of nervous reflexes which is expressed through an energetic contraction of the inspiration musculature followed by a rapid exhalation with closure of the glottal rim, followed by a reopening of the same accompanied by a sound vibration followed by an elevation of the soft palate which occludes the nasopharynx structure. Functionally, the cough occurs to expel accumulations of mucus from the airways, or a food bolus that risks going into the trachea or in any case due to the presence of irritating substances/events for the oropharyngeal mucosa. Since the occurrence of repeated bouts of coughing is one of the prodromal signs of an incipient COVID-19 infection [1], their detection certainly represents one of the indicators to be taken into account for the purpose of the sudden decision to direct the worker who manifests these symptoms towards the specific protocols to determine a possible infection with COVID-19 or not.

### *D. Cardiovascular and body temperature assessment by the face mask's sensors inside and around the ears*

As shown in figure 4, a thin, flexible arm connects the face mask both with the external acoustic meatus of the ear, inside which the interior body temperature sensor is positioned, and with the earlobe clamped by the pulse oxymetric sensor. As is known, when the partial pressure of oxygen in arterial blood ($P_pO_{2\text{-}a}$) falls below 100 mmHg, hemoglobin does not bind totally to oxygen as its chemical affinity for this respiratory gas is inversely proportional to $P_pO_{2\text{-}a}$. For this reason, when this blood that is not totally saturated with oxygen (in clinical practice a value that oscillates between 95% and 98% of the maximum is considered normal saturation since 100% is not physiologically obtainable due to the reflux of venous blood in the left ventricle from the coronary circulation of the heart) reaches the tissues, its oxygen content may not be sufficient to meet the body's demand for this gas. To detect the percentage of arterial hemoglobin saturation beat by beat in workers wearing the AG-47 SmartMask, a commercial pulse oximetry device was modified so that it could be clamped to an earlobe. This technology consists of two instrumented arms between which a fold of tissue abundantly supplied with capillary arterial blood must be placed, i.e. the ear lobe: one arm containing two light-emitting diodes and the other a photometric detector. The two diodes each emit a beam of light with a precise wavelength: 660 nm and 940 nm respectively. The light beams emitted by the two sources cross all the tissues of the ear lobe reaching the detector positioned on the other arm of the same probe, on the other side of the lobe. During its path, the light radiations are absorbed by hemoglobin: Hemoglobin bound to oxygen or oxyhemoglobin ($HbO_2$) absorbs mainly infrared light while hemoglobin not bound to oxygen (Hb) absorbs mainly red light. By exploiting this difference in absorption between $HbO_2$ and Hb, the device measures and analyzes the difference between the amount of light radiation emitted by the diodes and the final one detected by the sensor, returning the percentage of $HbO_2$.

Fig. 4 The lateral perspective in the dummy head wearing the AG-47 SmartMask shows both the intraural thermal sensor and the pulse oximetry sensor at the ear lobe

Heart rate per minute (HR) is also measured by the same pulse oximetry signal. For workers exposed to the risk of infection with COVID-19, the possibility of continuous heart rate monitoring is of great importance. In fact, the "National Health Commission of China" [1] reported that only after a long time were patients who showed up to the doctor with cardiovascular symptoms such as tachycardia, heart palpitations and chest tightness but without respiratory symptoms or cough and fever, diagnosed with COVID-19, but with myocardial damage. It is therefore strategic to be able to acquire the HR beat by beat through the AG-47 SmartMask for healthcare professionals working with COVID-19 patients. In fact, abnormal periods of excessive bradycardia or tachycardia or arrhythmias of various types, can be the prodromes of a more serious myocardial damage from corona virus even in the absence of respiratory symptoms and hyperthermia.

Since it has been observed that over 80% of cases of infection with COVID-19 have fever with values between 38° C and 39° C as a prodromal symptom [8], the AG-47 SmartMask is also equipped with a continuous detection of body temperature. Taking into account the ergonomic limits imposed by the prototype design, which aim to engage, for the set of clinical variable measurements provided, only the lower part of the face with two extensions of proximity to the ears connected to the mask in wireless mode, the AG-47 SmartMask allows such measurement by means of a micro temperature sensor placed as proximal as possible to the eardrum membrane. In fact, the measurement of body temperature through the detection in the tympanic proximity appears to be comparable to the measurements obtained at oral or rectal level [9].

### *E. Data acquisition process*

The data acquisition process carried out by each sensor in the AG-47 SmartMask is placed under the direct coordination of the device's control electronics. The main element of the electronic control system of the SmartMask consists of a Micro Controller Unit (MCU) which combines high computational performances with extremely low energy consumption levels (a STM32L4R5AI ARM-M4 Ultra Low Power MCU which core is an ARM 32-bit Cortex-M4 CPU). By exploiting these characteristics of the device's main microcontroller and making a pervasive use of power saving algorithms, together with wake-on techniques based on external events (detection of signal spikes, hardware watchdog timers and so on), it was possible to combine the performance of relevant computational tasks, relating to the analysis and storage of the acquired signals, with a minimum operating time sufficient to guarantee continuous use of the device for the duration of a typical work shift (8-10 hours), without the need to recharge the on-board power system (lithium-ion batteries).

The duration, frequency and characteristics of each sampling event implemented by each sensor making up the AG-47 SmartMask are directly controlled by the main MCU and can be configured via software, by means of direct upload of the configuration into the device firmware or through changes that can be made using the command and control protocol supported by the wireless connectivity in the Bluetooth standard. Changes to the device configuration parameters, therefore, can be transmitted from the AG-47 by means of an associated remote telemedicine platform (RTP) to a telemedicine center via direct Bluetooth connection (in the case of completely in-house scenarios) or via the control application operating on mobile devices (remote scenarios in-cloud).

Based on the configuration parameters present in the firmware or received from external systems, the MCU performs an orchestration of the sampling sessions of each sensor. The data sampled from each sensor of the AG-47 mask is acquired by the main MCU which carries out an analysis in real time. The purpose of the first level of analysis is both to filter the signal to reduce the disturbances present, thus increasing the Signal-to-Noise Ratio, and to extract features of interest.

As regards filtering, it is necessary to illustrate how, during the development phases of the prototype, a preliminary study was carried out during which a large number of traces relating to each parameter monitored by each sensor in the device were acquired.

These plots were used to develop models of Newtonian reference dynamics systems that are used to filter each signal by means of extended Kalman filters, in order to obtain an optimal estimate of the observed parameters. The signals thus filtered were subsequently processed by a features extraction module which performed a segmentation by means of predetermined or dynamically adapted confidence intervals, a morphological analysis, a search for local maximum and minimum points and an extraction of inflection points in order to identify the features of interest present in each segment of each signal.

At the end of the segmentation and features extraction process, the MCU proceeded to classify the recognized features to determine the physiological parameters of interest, as described in the previous paragraphs. Thus, for example, the classification of the barographic, thermographic and hygrographic curves led to the identification of the respiratory acts, cough events or sneezing. During the phase of classification of the features, the MCU carried out a further control task, applying consensus algorithms to the detected data, in order to be able to promptly identify any drift and malfunction of the device sensors. The consensus algorithms applied mainly focused on consent to the average and were implemented by means of counters contained in special data structures, allocated for each type of data detected on each sensor, which were dynamically updated during the time analysis carried out on these signals. Thanks to this control system, the MCU of the device can quickly assess the state of consistency of the sensors and the onset of any deviation or malfunction phenomena. Furthermore, the structure of the AG-47 SmartMask signal acquisition system has been designed with maximum flexibility, to support different usage scenarios and different product lines, suitable for multiple market targets.

Fig. 5 The image shows two workers engaged in their usual duties along the packaging chain of vegetable products, each wearing an AG-47 SmartMask whose periaural extension is not visible as it is placed in the left ear. It can be clearly observed that the inter-individual distance is somewhat reduced and for this reason the anti-COVID-19 facial protection device is certainly suitable.

Therefore, although the minimum expected SmartMask configuration contains the previously described sensors (a thermo-hygro-barometric sensor inside the mask, an intraural thermal sensor and an ear lobe pulse oximetry sensor), the device can be equipped with a greater number of sensors of each type.

## III. EXPERIMENTAL VALIDATION

### *A. Description of the chosen work environment*

In order to validate the AG-47 SmartMask, a limited number of specimens produced in pre-series were worn by the operators working in the horticultural product and packaging department of a production company operating in the precision agriculture sector (see figure 5). These subjects, both males and females, carry out work activities characterized by an energy expenditure considered light but which often forces them to act in groups with necessarily reduced inter-individual distances. Environmental temperature and humidity were respectively 22±4°C and 55±5%. The validation of the AG47 platform took place at the headquarters of one of the largest companies operating in the sector of precision agriculture, responsible for the processing and marketing of fruit and vegetables in the Region of Sardinia (Italy), in the territory of the Municipality of Sestu, in the province of Cagliari. The company headquarters is divided into an industrial warehouse of about 4,500 square meters within which over 30 employees work, assigned to the functions of receiving agricultural products conferred by associated companies, warehouse logistics, delivery of processed products to the company's customers and cryopreservation of products in storage in cold rooms. The entire area of the warehouse is equipped with a Bluetooth wireless network used for wireless voice control functions made available to logistics operators who, using electric vehicles to move goods, interact with the company system vocally, in a hands-free way. The platform was installed in a dedicated Kubernetes cluster separated at the network level from the rest of the corporate ICT architecture consisting of a set of 12 physical servers, in which virtual machines are operational (fully virtualized with QEMU-KVM virtualization) necessary for carrying out common business activities.

### *B. Anthropometric and functional characteristics of the workers admitted to the experiment*

Among the workers who volunteered to participate in the trial, 20 were enrolled, 12 of whom were male and 8 female. Their mean age was 41 ± 13 years with a weight of 63 ± 11 kg and a height of 1.61 ± 8 cm. In accordance with national and regional specific laws, every six months engaged workers underwent the occupational doctor visit which report is kept in the company files. Anyway, from the clinical history it was clear that none of them were chronically affected by cardio-respiratory pathologies or by endocrine-metabolic syndromes as well as by otolaryngological and haematological pathologies. All of them signed the informed consensus.

### *C. Experimental protocol and results*

The validation protocol of the instrumented face mask device was divided into the three phases as described below.

TABLE I

MEAN VALUES±SD FROM SENSOR VARIABLES

| Breath Patterns | Breath freq. (br/min) | $T_{Mask}$ °C | $RH_{Mask}$ % | $P_{Mask}$ Pasc | $T_{timp}$ °C | Heart freq. (be/min) | $HBO_2$ % |
|---|---|---|---|---|---|---|---|
| Eupn. | 14 ±4 | 28.6 ±2.2 | 88.3 ±1.2 | 101.3 ±0.5 | 36.8 ±1.3 | 63.6 ±11.1 | 97.3 ±0.3 |
| Tachip. | 27 ±6* | 27.8 ±1.9 | 92.1 ±1.6 | 101.9 ±0.7 | 36.7 ±0.8 | 66.6 ±13.6 | 97.4 ±0.5 |
| Rec. | 16 ±5 | 28.1 ±2.0 | 90.4 ±1.6 | 101.5 ±0.9 | 36.8 ±0.9 | 65.2 ±15.1 | 97.1 ±1.0 |
| Coughs | | | | 157.3 ±5.2 | | | |

* with respect to Eupn. and Rec.: $P<0.05$ (Student's t test)

After wearing the instrumented face mask while staying in their usual work station, each subject breathed quietly (subjectively eupnoic) for 10 min in order to adapt to the device worn: a) the remote variable acquisition system was then activated by the biomedical sensors embedded inside the face mask while the person on duty continued to breathe spontaneously for another 3 min; b) at the end of the third minute the subject carried out a sequence of 5 tachypnoic and superficial breaths (thus simulating the condition of COVID-19 dyspnoic breathing); c) recover, at the end of voluntary tachypnea, of the eupnoic respiratory activity for a further 3 min and then voluntarily provoking 3 coughs. Table I shows mean vales of the respiratory frequency and of the other biophysical variables assessed during the three experimental phases. (Statistic package: MedCalc, 8400 Ostend, Belgium).

## III. DISCUSSION

Data from the above experimentation reasonably allow us to affirm that the AG-47 SmartMask with the dedicated RTP is a suitable tool to be utilized from workers operating in high risk environments for COVID-19 infection. In fact, from a methodological point of view, the simulation of a non-ergogenic tachypnea was reliable since during the voluntary tachipnoic phase a respiratory frequency was obtained which, on average, was double compared to the previous eupnoic phase. As expected in healthy subjects, experimental phases did not show variations for HR and $HBO_2$ as well as the values of $T_{Mask}$, $RH_{Mask}$ and $P_{Mask}$. It is also of not negligible importance that the simulation of coughs gives rise to an increase in intra-mask pressure of over 50% compared to eupnoic breathing.

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