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*Research Article*

# A Plurisensorial Device to Support Human Smell in Hazardous Environment and Prevent Respiratory Disease

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Products embedded with wearable technologies can be a useful tool to support humans' senses in situations where they can be insufficient, mistaken, or misleading. In this article, we discuss the findings of a two-year Transnational European Research Project named "POD: Plurisensorial Device to Prevent Occupational Disease." The research was based on the evidence that human senses are not always reliable in making objective judgments. The specific field of application was coating plant, an environment that exposes workers to the risk of inhaling dangerous particles. The results obtained in the first part of the research pointed out that workers, largely relying on their sense of smell, which instead is often untrustworthy, do not protect themselves enough. Based on this ground, we designed a wearable system for providing workers with objective data both on their respiration activity and on the quality of the air in the working environment, with the ultimate goal of engaging them in wearing their personal protecting equipment (PPE). The article describes the development and testing of the solution; an example of how wearable technologies can enhance senses and improve workers' health.

## 1. Introduction

A report of the Scientific Committee on Occupational Exposure Limits (SCOEL) published on June 2014 highlighted that 15% of all adult respiratory diseases are a consequence of work-related exposures. Within working environments, volatile organic compounds (VOC) are one of the highest causes of asthma, lung cancer, chronic obstructive pulmonary disease, cystic fibrosis, and respiratory tract infections. Following this data, the Research Project, "POD: Plurisensorial Device to Prevent Occupational Disease," was carried out by the Design Department of Politecnico di Milano, in collaboration with the Department of Design Engineering from Delft University of Technology and Comftech, an Italian company specialized in smart textile. The project faced the issue of coating plant environments, where workers are highly exposed to the risk of inhaling hazard substances. According to the International Labour Office, prevention is the best way to reduce the number of diseases and improve workers' health. There are two levels of prevention: (i) environmental monitoring and (ii) the use of personal protective equipment (PPE). PPEs are mandatory by law but, despite this, their usage is comparatively sparse. The objective of the research was to understand why the use of PPEs is still poor and verify if the design of a wearable system based on sensor technology could enhance users' awareness about the importance of wearing protective devices.

Our research started with both a general exploration of human senses, focusing on smell, and an analysis of how workers perceive the environment through their senses.

## 2. How Workers Sense and Act

In order to understand how workers sense and act, we needed to both interview and observe them in a real coating plant. For such an analysis, the choice of the proper participants was relevant. Thanks to the support of Anver (Associazione Italiana Verniciatura, i.e., the Italian Painting Association), three SMEs from the northern area of Milan were identified. These three companies perform similar activities within their coating plants: coating of furniture and of small-to-medium mechanical parts.

Figure 1: Workers working in a cabin.

The three chosen coating plants have less than 20 employees. The main reason for this choice was that, in large companies, the operations of lacquering and finishing are often automated (i.e., performed by robots). Moreover, in small companies, it is easier to establish a direct contact with workers, to observe their behaviour, and to collect useful feedbacks. The first company is specialized in finishing and lacquering of metals and polymers, and the second one in finishing and lacquering of wood, steel, and metal, and so does the last one.

The user analysis, performed in each of the three companies, was divided into two parts: (i) observation: analysis of workers' behaviours in order to understand if and how they use current PPEs; (ii) interviews: with both workers and employers, in order to figure out which was their perception about the risk in the working place, what was motivating/demotivating workers in wearing the personal protective equipment, and if they were willing to accept an interactive monitoring system.

Both observation and interviews were led by three researchers and involved a total number of twenty workers (one woman and nineteen men) and were carried out between December 2015 and January 2016. We first observed the workers while performing their tasks, and then we submitted an interview addressing four main topics: (1) working activity and protective equipment, (2) mask's aesthetic and comfort, (3) safety perception, and (4) the use of personal technological devices. Hereafter, our main findings are described.

First of all, in each analyzed coating plant, we noticed the presence of a cabin where the lacquering activity is performed (see Figure 1). The cabin is equipped with an aspiration system that takes away the varnish particles from the indoor environment, so as to reduce the inner air pollution.

While in the cabin, all workers are supposed to wear a Personal Reusable Protective Mask for their personal safety but, as far as we observed, they do not. Indeed, even if the Volatile Organic Compounds (both in powder and liquid paints) have a very strong smell, after a while, getting used to such odours, the workers' perception about them decreases. Therefore, not perceiving the smell intensity anymore, they do not feel any necessity to wear the protective mask, despite being regularly exposed to dangerous particles. These workers are indeed experiencing the so-called "adaptation phenomenon," that is, the reduction in the perception of an odour following a long-term exposure to it [1].

We were really able to experience such adaptation: indeed, both during the observation and the interviews, workers were comfortable and did not seem to perceive any bad odour, while we had a completely different perception. One of us started coughing and had to leave the cabin, another one immediately felt irritation of her respiratory tract and saw blue particles (a worker was using a blue paint) on the tissue after blowing her nose, and the last one hardly stopped sneezing.

All the interviewed workers (20) stated that they wear the Protective Mask just when the so-called overspray is visible, a circumstance that occurs only when they are painting large objects or object with a complex geometry. In addition, they trust the factory aspiration system, judging it enough to protect them from the inhalation of dangerous particles and prevent them from respiratory diseases.

Other reasons for not wearing any protection are the following: the mask's discomfort due to the stiff connection to the face and the poorly breathable fabric, suffering from skin allergies (especially during summer time), and being distracted and forgetting about them. All the interviewed workers asked for a new mask designed with more attention to wearability and comfortable materials.

Moreover, the user session made it explicit that each worker relies on his/her own sense of smell and that, being immersed in the same environment, the workers tend to conform to the behaviours and opinions of others. Since their smell is altered, their perception towards the possibility of severe diseases (i.e., incurring in lung cancer, chronic obstructive pulmonary disease, cystic fibrosis, and respiratory tract infections) is modified. So, the problem becomes even more severe—workers are likely to rely on both their and other ones' subjectivity. We listened to statements like: "Well, he has been working here for ten years. If he is not wearing the mask, it means that it is not necessary"; "If all my colleagues wore the mask, I would do it as well."

According to the World Health Organization and Europe Mortality database in 2011 in Europe, it was estimated that a total of 7200 cases of respiratory diseases were related to occupational exposures to VOC and dust. The annual Inail (i.e., Italian National Institute for Insurance towards Works related Injuries) Report from 2015 confirms the European trend, putting respiratory diseases at the third place (13,5%) in Italy among occupational ones, also stressing the severity of their consequences. Such data show the importance of wearing PPEs in order to prevent the inhalation of dangerous particles.

To us, also thanks to our personal experience in the coating cabin, the severity of the risk was evident. Furthermore, an emblematic story was told to us by a worker: his father, a nonsmoker, used to work in the same coating plant and died from lung cancer at the age of 65. Despite that, the worker at stake does not perceive the correlation between not wearing the mask and getting sick. Therefore, he does not protect himself. This story, together with the statistical data related to respiratory diseases, reinforced our willingness to introduce a medium to support workers' sense of smell and sensitize them towards the use of PPEs.

The investigated workers are not fully aware of the importance of regularly wearing protective equipment since, without feeling bad odours anymore, they do not perceive Volatile Organic Components as dangerous to their respiration system. They are thus trapped in a vicious circle: being used to certain odour reduces perception; reduced perception is disabling seizing of risks. Until confronted with an "abstract" concept (i.e., protecting their health), it is hard to make people change their behaviour; they need to perceive a tangible benefit [2]. Giving a tangible benefit, in this case, could mean excluding subjective opinion by introducing objective data that can enhance the workers' perception making them aware of the risk they are taking.

As already noted, besides the lack of proper odours perception, the workers do not wear the mask because of comfort issues. They all stressed that if the mask had been more comfortable and made of different materials, they would be willing to wear it more regularly. This was another important insight to be taken into consideration in the next steps.

Regarding the embedding of technology, it was necessary to understand if and how users were willing to accept the idea of wearing a technological apparatus and if they had any kind of preparation related to technologies. We thus described to our potential users the possibility to have a wearable system informing them about the quality of the air and monitoring their personal vital parameters. 85% of them responded that they were interested in having feedbacks about the air quality and their vital parameters. They stated that, confronted with evidences about their exposure to chemicals and their health status, they would be more motivated to wear the protective mask.

## 3. The Human Sense of Smell

The user session with the workers of the three coating plants confirmed us that smell, as all human senses, may generate a perception that is not fully realistic. Even if we are not always aware of it, our sense of smell plays a very important role in our everyday life, constantly monitoring the environment around us. In any moment of our live, we perceive different odours: from the coffee we drink in the morning to the soap we use for washing to the fabric softener of the clothes we wear. In general, smell's three main purposes are (i) the detection of hazards, (ii) the detection of pheromones, and (iii) the detection of food.

However, human senses have their limits that can be made more evident by factors as habits, illness (e.g., a cold is sufficient to neutralize our sense of smell), or pathology. Due to such limits, our senses can be deceived, as is evident in any case of optical illusion [3, 4].

In our case, the most important feature to stress is that, among all human senses, smell is the one that "get bored" more easily: when entering a florist or a pastry shop, we are very aware of all the aroma surrounding us but after some minutes we are no longer able to smell them. Humans have the tendency to get used to odours, at the point that they do not perceive them anymore or not with the same intensity as before [3]. According to Dalton and Wysocki, "Any individual living or working in an odorous environment can experience changes in odour perception, some of which are long lasting. Often, these individuals report a significant reduction in the perception of an odour following long-term exposure to that odour (adaptation)" [1].

This phenomenon can be readily observed in situations where ambient odours are chronically present as for the case of workers in the observed coating plants. Individuals who live or work in such an odorous environment often report that, with continuous exposure, their perception of the ambient odour intensity is greatly reduced. Furthermore, as we noticed with our users, the perceptual changes that result from daily exposure can be quite profound and durable. For example, it is commonly reported that, following extended absences (hours to days) from the odorous environment, reexposure to the odour may still fail to elicit perception at the original intensity [5]. In our case study, this perceptual change seems to represent a very persistent kind of adaptation.

## 4. Wearable Technology and Sensors

When the limits of our senses endanger our health, it might be the case to introduce a technological medium. Technology might resolve the problem of subjective perception by collecting objective data that can be communicated to users through smart devices. If well designed, such communication can reach the aim of changing humans' habits and behaviours without coercion [6].

In our idea, technology could enhance workers' perception of risk, providing them with objective data to base their decision on wearing PPEs upon. We focused on the use of smart technologies belonging to the class of wearable technology, which represents a large and rapidly increasing research area in sectors like medical devices, electronics, textiles, and telecommunication [7]. The purpose of wearable technologies is indeed to facilitate everyday life and also protect and inform users in order to avoid human errors, as those related to subjectivity of senses and perception [8]. These technologies are mostly based on sensors [9] and can monitor and/or stimulate, treat, and replace biophysical human functions. This way, wearable technologies led towards a stimulation and extension of our sensoriality [10].

Nowadays, the market offers wearable devices like the Philips Respironics CAPNO2mask Mainstream Monitoring Mask, a noninvasive mask for adults with respiratory disease which simultaneously delivers oxygen and measures mainstream end-tidal $CO_2$. Another example is the IBM Employee Wellness and Safety solution, an IoT solution for preventing

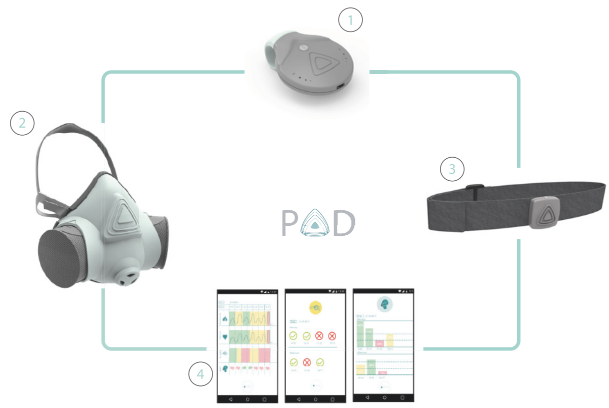


Figure 2: POD Interactive Protective System: (1) Electronic Nose Device, (2) Personal Protective Reusable Mask, (3) Chest Band, and (4) Mobile Application.

injuries at the workplace in different industries. IBM provides to workers the mobile app that operates in real time and informs the worker about the potential work-related risks.

Besides few examples like the above-mentioned two, in the field of health, wearable technologies have so far predominately focused on diet and physical activity, motivating physical activity and maintaining exercise routines. A good example is JAWBONE, a wrist-band that monitors and tracks the user's sleep, activity, and diet. All the data are provided to users via a mobile app. Another widespread use of sensor technology, usually not wearable, is outdoor or indoor environmental monitoring aimed at informing users about pollution in their cities, homes, offices, and so forth (i.e., Electronic Nose by NASA; TZOA by Woke Studios; Speck™).

Despite sparse applications, in our case, a wearable system could give more control to the user by focusing on risk prevention. According to IJsselsteijn et al. [11], in the next years, one of the strongest areas of innovation related to wearable technologies will indeed regard preventive health systems.

The value of wearable technologies also lies in their proximity to human body, synthetized in the paradigm: anytime, everywhere, and by anyone [12]. They can provide real-time feedbacks, informing the user immediately if something goes wrong.

## 5. Overcome the Weakness of Smell: POD Wearable System

*5.1. Method.* The insights from the user session, confronted with the literature review, let us to reason about designing the wearable system named POD (Plurisensorial Device to Prevent Occupational Disease) based on sensor technology that monitors both the air quality and the worker's vital parameters. Our aim was to influence the perception of risk by workers, so as to motivate them to wear the protective equipment. We generated the entire system according to the results discussed in Ferraro et al. (2018) [13], following the typical phases of a design process [14–16]:

(i) User Analysis: it lasted four months (participants selection, user observation, and semistructured interviews) engaging a total number of twenty workers.

(ii) Ideation Phase: it included a concept generation phase and a focus group with users to select the most promising concept. It lasted four months.

(iii) Concept Development: it lasted eight months and was related to the engineering and the prototyping of the system.

(iv) User Testing: it lasted two months and was performed within the first of the analyzed companies thanks to very open-minded owner willing to innovate and experiment.

We developed a system made up of (i) a wearable alert device called the Electronic Nose Device, (ii) a Smart Personal Protective Reusable Mask, (iii) a Chest Band, and (iv) a Mobile Application (Figure 2). The system POD was both engineered and prototyped.

The Electronic Nose Device, illustrated in Figure 3, gives real-time feedbacks to the user about the air quality in the coating plant. It replaces the human nose in sensing the environment. It is based on a Volatile Organic Compound sensor that monitors the level of Volatile Organic Compounds (VOCs). The selected sensor module (USM-MEMS-VOC) is based on a highly stable TGS 8100 semiconductor MEMS sensor. This module uses short response times and measurement cycles thanks to specific Digital Sampling Technology (DSP). Additionally, this sensor needs less than 20 mA in continuously operation mode and it requires 1,8V voltage supply which is suitable for an application as ours, where the device has to be operative up to 9 hours. Another advantage was the small dimension of the module (17x15x3mm) which makes it suitable for the implementation in wearable devices.

The Electronic Nose gives feedbacks leveraging on two senses not altered by the working environment: the vision and the touch (Figure 4). Indeed, the RGB LED placed on the PCB board provides three different colors: green (everything is fine), yellow (the situation is getting dangerous), and red (the VOC concentration is very high) associated, respectively,

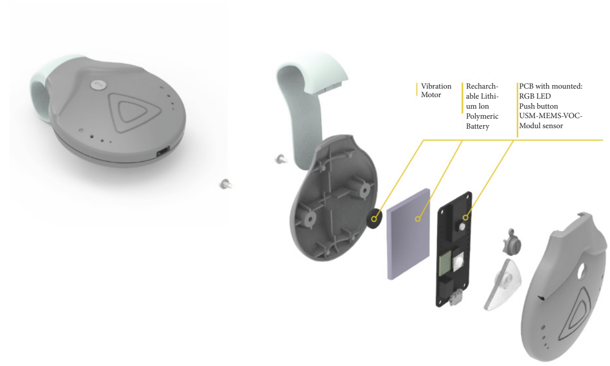


Figure 3: Assembly of Electronic Nose Device with electronics.

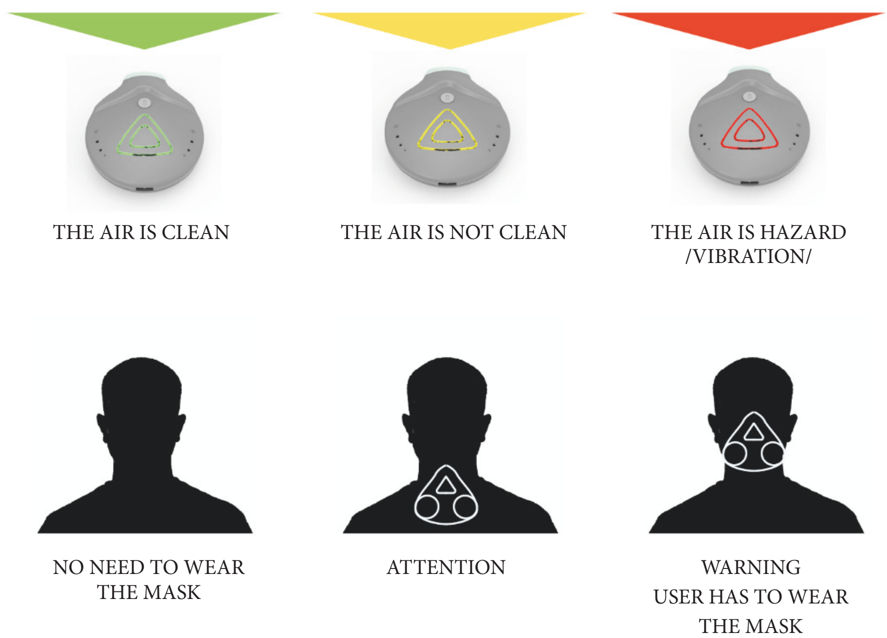


Figure 4: Feedback about air quality Electronic Nose Device.

with no vibration, low vibration, and strong vibration. The data gathered from the VOC sensor are transmitted and stored via Bluetooth technology (BLE module integrated on the PCB) to the mobile app. These data can be visible to the user not only in real time but also as a long-term passive feedback, by showing both the daily output about the air quality and the air quality chart over a longer period (i.e., weekly or monthly report).

Such a device becomes a medium between the human senses and the environment, supplying the reduced perception of the smell and reminding workers to wear the mask in order to safeguard their health.

We also redesigned the mask, evaluated by the interviewed workers as unpleasant to wear. We decided to solve such a problem by focusing on the use of alternative materials (see Figure 5). In order to improve the transpiration and reduce the risk of skin irritation during summer, we replaced traditional rubber with a thermoformed spacer textile padded with soft foam. In order for the mask to be softer and smoother in contact with the head, we used thermoformed textile for the laces.

Another problem highlighted in the user session was the weight of the mask. For this reason, we decided to use the nonwoven thermoformed fabric for the carbon filters that are then welded to the mask's base. This way, by decreasing the use of plastic pieces, we reduced the overall weight of the mask.

The mask is also equipped with a temperature and humidity sensor aimed at monitoring the user's breath (humidity and respiration frequency) and checking if the mask is worn: if the mask gets in contact with the face, the sensor automatically turns on and the information is transmitted to the Mobile Application via Bluetooth. Here we choose to integrate the Sensirion SHT31 sensor which relies on innovative CMOSensor® technology that makes it very accurate. Considering that we needed a sensor easy to

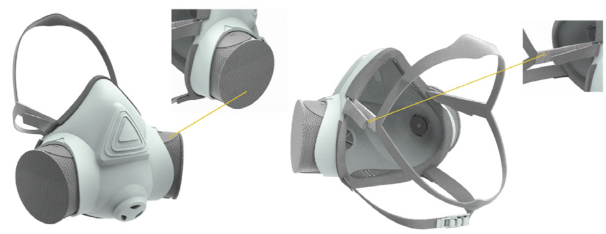

Figure 5: New mask design with thermoformed nonwoven textile filter bag and lacing detail.

Figure 6: Mobile App for the worker.

integrate in the protective mask, SHT31 was a suitable choice due to its small dimensions (2,5x2,5x0,9mm—slightly bigger if integrated as a module on the PCB). It is a low power consumption sensor; it uses supply voltage between 2,7V and 5.5V and the energy consumption is equivalent to 4,8 $\mu$W.

The Chest Band (Figure 6) is a textile band sensor to be worn under the T-Shirt throughout the entire working day. It monitors the user's breathing frequency.

All the data gathered by the three devices (i.e., the Nose, the Mask, and the Band) are transmitted via Bluetooth to a mobile application (Figure 6) that gives the user three simplified parameters: breathing rate, air quality (related to the level of VOC), and Protective Mask wearing frequency.

Thanks to the Application, the user has a complete account of his/her behaviours and physical parameters - if he/she was wearing the Protective Mask when the air was polluted and how and when his/her breathing frequency was getting worse.

These data are shown both on a daily basis and in a weekly and monthly statistic. Statistical data are intended to increase the visible benefits in wearing the Protective Mask: the worker is able to see the health progress made thanks to the mask. Indeed, he/she will realize (see following section) how his/her breathing frequency improves while wearing the mask.

This way, we created a wearable system with several features: (i) complement the human nose in real-time sensing of the environment, (ii) monitor the user respiration giving feedbacks to increase awareness about personal health, and (iii) show statistical data of the Mask wearing frequency in relation to the presence of dangerous particles.

Nowadays, the use of PPEs in dangerous working environments is the only way for workers to prevent serious disease. Existing personal equipment are "static" products. We instead developed an interactive system, made up of "dynamic" products empowered with sensors and technology.

## 6. Results

The wearable system (see Figure 7) was first prototyped and then tested with end users, in order to assess its qualities and flaws. In general, we wanted to check if and how the system would be perceived useful to enhance senses and improve users' health.

In more details, one of the most important objectives of this test was to understand if representing data as gradual chromatic change rather than numbers was clear and motivating for the users. At this stage, we did not focus on technical issues related to the device's precision.

Before the user testing, our expectations were that (i) the electronic nose would be a useful wearable solution to support human smell; (ii) the redesign of the Mask, improving its aesthetics and wearability, would reduce barriers in wearing it; (iii) the data elaborated by sensors would be transmitted to the user in a clear manner.

Figure 7: Mask, electronic nose, and chest band prototype.

Figure 8: On the left, worker in a cabin wearing Electronic Nose Device. On the right, worker getting near to the paint with Electronic Nose Device.

The testing of the prototype carried out in May of 2017 [13] on a total number of five workers was framed into two phases: a general observation coupled with data recorded by the sensors and collected in the working space and an unstructured interview aimed to have general feedbacks about the system and understand its efficacy. The observation was made up of two steps: (i) the workers were asked to wear the chest band and to use the electronic nose for 30 minutes; this step was useful to figure out if they understood the functioning of the electronic nose (see Figure 8); (ii) they wore both the electronic nose and the mask for 30 minutes as well (see Figure 9). We carried out five different sessions with different workers for a total number of 5 hours of testing, followed by the unstructured interviews submitted to each worker.

The functional prototypes of the Protective Mask, the Electronic Nose Device, and the real Chest Band allowed us to control the vital and environmental parameters during the observation, while the users received real-time feedbacks. The sensors showed the breathing rate value and VOC consistence in the air. These parameters were observed both when the Protective Mask was worn (on) or not (off). The purpose of comparing these parameters was to understand whether the efficacy and accuracy of sensors' information were good and fast enough and to confirm the theory that the hazard substances in the coating plant influence workers' breathing and to check whether something changes when the Protective Mask is worn.

We were following the results about air quality and breathing rate trough a demo of the mobile application. The devices (Electronic Nose, the Mask, and the Chest Band) were connected to the Mobile App via Bluetooth connection. The workers were performing working actions in the cabin, the same that they execute normally, wearing first just the Electronic Nose and the Chest Band and then also the Protective Mask.

In Figure 10, we can see how the wearable system displays the monitored parameters: (i) changing the dot colour from red to green according to the air quality; (ii) thumbs up or down for the wearing of the mask; (iii) breathing graph. It can be seen how all the parameters are interdependent. In the first image, we can see the results for breathing rate and consistence of VOC in the environment when the Protective Mask is not worn (figures on left side). In the right-side figure, we show and compare the same parameters when the mask is worn.

During the session, we noticed that the air quality was not constant. Before starting the activity, in the cabin any air contaminant was not present: indeed, the device remained on the "green" range that we identified between values of 0 and 255 (on the scale of analog read between 0 and 1023). When the activity started, the line on the graph started to increase and, depending on the distance between the worker and the object to be painted, it was increasing or decreasing. In general, we found that the level of contaminants tends to remain on the "yellow" range, numerically the range between 255 and 511 (on a scale of analog between 0 and 1023). This means that the mask wearing is required. In the presence of overspray, the line on the graph was increasing up to the "red" range, numerically the range between 511 and 767, in which wearing the mask becomes necessary. This occurred when concave objects were painted. Another case in which the line was in the "red" range was when the worker was opening the painting can, mixing and pouring paint. Summarizing the results, wearing the mask was required almost at any time. Quantifying the results, from the plot time-contaminants emerged that over one hour, 40 minutes were signaled as yellow and the remaining 20 minutes as red.

Wearing all the elements of the system during the observation sessions allowed the workers to evaluate the comfort, the materials, and the overall wearability. The observation was video-recorded, and the data collected from the prototypes were saved and subsequently analyzed. After the observation, each user was asked to partake in an unstructured interview.

The results gathered from the general observation, the sensor measuring, and the unstructured interviews gave an overview of the system efficacy in changing the consciousness of workers towards their health conditions.

The Electronic Nose was considered a necessary element in any coating plant. The workers appreciated the possibility

Figure 9: On the left, worker wearing the mask in cabin. On the right, worker wearing Electronic Nose Device, Mask, and Chest Band.

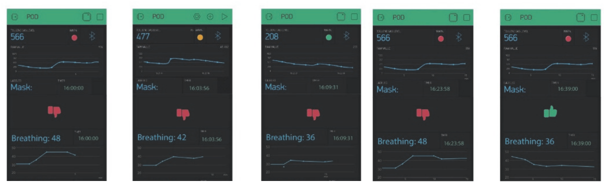

Figure 10: Monitoring results.

to wear it in a versatile way: on the pants' pocket, on the shirt's collar, and on the shirt's sleeves. The most important feature of the Electronic Nose, the feedback in form of light and vibration, received a very good evaluation. Both the employer and employees were interested in wearing one. Sentences coming from the users were the following: "Wow, I feel safer with this device"; "I would like to have it, so I would know how my breathing is and when I certainly need to wear the mask"; "It makes me feel superhuman, it smells what I'm not able to feel in the environment."

Regarding the Protective Mask, workers evaluated rather positively its wearability and general comfort; they liked the materials and the overall look of the new design.

The Chest Belt was evaluated as a noninvasive element; workers found it very comfortable and easy to understand.

The functions of all the elements resulted to be clear to users and the Mobile Application perceived quite understandable both to the workers and the employer. They were able to read the feedbacks in real time, understanding the functioning of the whole system.

The employers specifically found the electronic nose and its data on the application useful to check the efficacy of the factory aspiration system over time.

## 7. Discussion

A systematic literature review on wearable systems showed that personal monitoring systems on the market today provide mainly single-parameter assessment and transmission and that there is currently no smart wearable system available that integrates biosensors, intelligent processing, and alerts to support users in improving health [14]. According to the same article, "to fully realize the health and wellness benefits of smart wearable technologies, researchers and providers have to work towards adoption of these technologies by studying user requirements and developing a comprehensive approach to health and wellness services."

The research project described here started in June 2015 and lasted two years. It was executed taking into consideration the following:

(i) The Scientific Committee on Occupational Exposure Limits (SCOEL) rates that 15% of all adult respiratory diseases are a consequence of work-related exposures and are caused by the so-called Volatile Organic Compounds (VOC).

(ii) According to the International Labour Office, prevention is the best way to reduce the number of diseases and improve workers' health.

The aim of the research project was to develop a wearable device able to support the human sense of smell, therefore preventing respiratory disease. This is a novelty, since in the field related of wearable technologies, the emphasis is generally given to the ability to elicit conscious health life style, such as doing exercises (Kidd and Breazeal, 2006; Ruttkay et al., 2006; Bickmore et al., 2004; Goetz et al., 2003; and Gockley and Mataric, 2006) [15–19], giving social support (Kidd et al., 2006; Kriglstein and Wallner, 2005) [20, 21], and helping with lifestyle change (Bigelow et al., 2000; Looije et al., 2006) [22, 23]. Moreover, there are no evidences in the use of wearable technologies to "support and enhance human senses."

In this project, what we really wanted to achieve was to give more control to the *"user,"* developing a product that is *"personal"* and *"tailored"* on the specific topic of respiratory disease by focusing on *risk prevention*. The added value is the dimension of *wearable technologies* whose peculiarity is also to fulfil the paradigm: anytime, everywhere, and by anyone.

Researches in field of wearable technologies have been around for a century and have always been the domain of engineers [14]. As Buchanan states [24], engineers are used to design for the "necessary," while designers design for the "possible." We aimed to develop an effective system able to provide objective data to the user, but we were very much concerned with how to provide those objective data and give a shape to the wearable technology.

We wanted to understand if and how wearable technologies could be perceived as an added value by workers who are subject to the reduction in the perception of odour because of the adaption phenomenon. We did not want to reason, as engineers do, on the mere *function* and *performance* but on *how valuable* is considered the use of wearable technology for the final user.

Based on those assumptions, we decided to develop the entire research activity by using a human-centered design approach, an approach to problem solving that incorporates the wants and needs of end users in every stage of the project by using qualitative methods.

The added value given by qualitative methods (observation, interviews, and focus group) is to focus on the user and his/her problems, that is, the core of the system, rather than on just functionality.

Indeed, according to Creswell [25], the use of qualitative methods is useful to explore and understand the meaning that an individual or a bunch of users belonging to the same target group confer to a specific social problem that, in our case, is the weakness of smell in the perception of risk.

## 8. Conclusions and Further Developments

Human senses are fundamental to interpret the world surrounding us. However, they have limits. In this article, we focused on the limits of our sense of smell.

The observation of workers within three different coating plants confirmed what is already well known in literature: our olfactory receptors get used even to strong odours if they are exposed to them over a prolonged period of time, ending up in not being able anymore to properly sense them. The long exposure to the same odour generates a significant reduction in its perception (adaptation phenomenon). Such adaptation is the main cause, for the workers we observed, of the lack of consciousness about the bad quality of the air they are inhaling.

Human practical behaviours are closely related to our sensorial perception of the environment: if the odour of potentially hazard substances (Volatile Organic Compounds) is not perceived anymore, the resulting behaviour will not be adequate to the situation. Indeed, workers do not wear Protective Equipment because they do not sense any risk.

However, when our health is in danger, the subjectivity of human perception should be overcome by introducing a technology able to complement it, so as to elicit behavioural changes. Nowadays, the development of microelectronics gives the possibility to integrate sensors in light and wearable devices, able to monitor the environment and provide users with real-time feedbacks.

The added value of wearing wearable technologies is in the possibility to provide the user with objective data and an immediate feedback, instead to rely on the subjectivity of our senses.

The overall aim of the described research project was to safeguard health condition of workers of coating factories by two actions: increasing their awareness of health risks and inducing them to wear Protective Equipment. We pursued our aim designing three interactive devices based on existing sensorial technology. The results of the user tests seem to be promising: they gave us a first confirmation that the designed system can be a valuable proposal. Nevertheless, more research is required to demonstrate the effectiveness of the system.

The research project resulted in two international patents: "Plurisensorial system adapted for the prevention of professional diseases in the working environment and method for the use of the system" and "Wearable device for controlling gaseous pollutants."

Since March 2018, the two patents are object of a research project entitled "User empowerment: shaping technology to change user behaviour" funded by the company BLS (https://www.blsgroup.it) that develops and sells respiratory protection devices. The objective of the collaboration is to improve the system and test it on a wider population of users not only in coating plants but also in other sectors where the presence of VOC is very high such as chemical industries, manufacturing companies, and agriculture. Moreover, we want to test it at a European level, in region like Spain or Netherlands, where branches of BLS are established.

In collaboration with the company, we are in the process of exploiting the results of the POD project and of translating them into a commercial product. So far, an improved working prototype was developed and tested in five different working environments (i.e., building sites, coating plants, and manufacturing companies). The results are promising and will be released in the next two months.

## Data Availability

The data used to support the findings of this study are included within the article.

## Conflicts of Interest

In accordance with ethical obligation as researchers, the authors declare that they have no financial, commercial, legal, or professional relationship with other organizations or with the people working with them, which could influence their research.

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