Chapter 3

Wearable Technology as a Tool to Motivate Health Behaviour: A Case Study

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Additional information is available at the end of the chapter

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Abstract

According to the Scientific Committee on Occupational Exposure Limits, work-related exposures are estimated to account for about 15% of all adult respiratory diseases. Today, the use of personal protective equipment (PPE) is the only way for workers to prevent disease. Nevertheless, its use is highly sparse. Currently, products and systems embedded with wearable technologies are able to protect, motivate and educate users. The authors then suggested the development of a novel wearable system following the beliefs that wearable technology can be persuasive and elicit a conscious behaviour towards the use of the PPEs by consequently improving their health condition. The authors here describe the result of a Transnational Research Project named "P_O_D Plurisensorial Device to prevent Occupational Disease." The chapter describes the findings achieved so far, the research phase and the new wearable system conceived as a possible example of how to use wearable technology as a useful tool to influence behavioural change.

Keywords: wearable technology, persuasive technologies, behaviour change, wearability, health, human-centred approach

1. Introduction

The World Health Organization and Europe Mortality database in 2011 in Europe, estimated that 7200 cases of respiratory diseases are related to occupational exposures to Volatile Organic Compound (VOC) and dust. The Annual Inail (Istituto Nazionale Assicurazione Infortuni sul Lavoro) Report from 2015 confirms the European trend, putting in Italy the respiratory diseases at the third place (13.5%) between the occupational ones, also stressing the severity of their consequences. Volatile organic compounds (VOC) are—within working environment—one of the highest causes of asthma, lung cancer, chronic obstructive pulmonary disease

(COPD) and respiratory tract infections. Moreover, the occupational disease percentage increment, in particular respiratory related diseases, is typically present in sectors such as agriculture, transportation and manufacturing which is considered also as the most dangerous with 5.172 cases of respiratory diseases in 2014 (INAIL). This text is funded on results gained from Transnational Research Project (SAF€RA Joint Call 2014) called "POD-Plurisensorial Device to Prevent Occupational Disease" which was developed by a consortium made up of Department of Design of Politecnico di Milano, Department of Design Engineering from Delft University of Technology and the Italian company Comftech. This project took place from July 2015 to August 2017. The data about the respiratory diseases shows the importance of wearing personal protective equipment (PPEs) preventing the users from the inhalation of dangerous particles. Starting from those data, the research project targets the development of a protective wearable system concept that is able to prevent respiratory diseases inside the environment of a coating plant.

The best method to reduce work-related diseases and improve general health of workers is prevention (International Labour office). Prevention can be done on two levels, which are (1) environmental monitoring and (2) the use of Personal Protective Equipment (PPE) which is also mandatory but often neglected by workers because they do not see the benefits of wearing it. A way to encourage the use of the PPEs could be to make workers aware of work-related risks they undertake and their health status by exploiting persuasive technologies in the shape of wearable devices.

Nowadays, the emerging smart technologies are able to support humans and can be persuasive and change humans' habits and behaviour without coercion. Intelligent technological products are able to change users' behaviour and educate, rather than only inform or do something for humans [1]. Technology might resolve the problem of subjectivity and precision by collecting and providing objective data that are based on real values of monitored subjects, objects and environments. In this perspective, technology becomes a sort of a prosthetics for human beings; it empowers human beings. Persuasive technologies are defined as "computer-based tools designed for the purpose of changing people's attitudes and behaviours" [2].

The authors investigated in particular the use of smart technology that belongs to the class of wearable technology. Wearable sensors and systems are defined as wearable sensors/actuators and sensor-based communicative systems that can monitor and/or stimulate, treat and replace biophysical human functions. Wearable technology's purpose is 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 [3–5].

Development of this research project consisted also in investigating technological solutions from other fields of study that have a similar purpose, as those in particular: medical (i.e. wearable monitoring systems for physiological parameters) and military solutions (i.e. the electronic nose developed by NASA). The main aim of the project was to create a meaningful interaction with the device able to motivate users to wear PPE by enhancing their consciousness related to the risks in the working place. Here the technology is supposed to make risks perceivable to users by obtaining valuable interaction [6]. The entire research was based on human-centred approach that relates wishes and needs of users, considering engagement of them in design process. Engagement of the user in design process was executed in repetitive cycles divided in five design phases: empathy, define, ideate, prototype and test [7, 8]. In this chapter, the authors describe the entire design process that led to the generation of a new novel wearable system by involving and emphasising with the user in every step to define his/her expectations. This is in order to translate those expectations in a way where wearable technology is shaped purposefully for the final user by becoming a powerful tool to change their habits in the use of the PPEs.

2. Wearable technology to persuade

Nowadays technology is taking over in different disciplines and with a different purpose: education, medicine and in general wellbeing, working environment, smart home, and so on. (Smartphone, smart watches, smart meter, run trackers, etc.). New Technologies have become deeply embedded in our ordinary everyday experiences by improving the way products and systems help, inform, engage and/or entertain us, coding new languages of communication and interaction. Different technologies change the way the people behave (interact) and also define the behaviour of artefacts, environment and system [9]. Technological products are able to motivate users and change their attitudes and behaviour but also to act beyond human capabilities. Donald Schön [10] defined "extension of human capabilities" as a main goal of technology.

On the other hand, as Fogg stressed, technology can be persuasive and change user behaviours. "Persuasion is a non-coercive attempt to change attitudes or behaviours" [11]. Interactive technologies have been—and will continue to be—created to influence (persuade or motivate) people in different fields of application. Interactive products able to persuade and motivate users are evolving in parallel with a technological development and level of adeptness of users to different forms of interaction with advanced products, systems and environments. Recently, persuasive technologies are developing also with a purpose of improving health and wellbeing, among those commercial based on computers and Web applications as a principal tool of interaction (i.e. selling products or services).

Advanced technologies and solutions and information communication technology (ICT) have potential to be a tool for promoting positive health and lifestyle habits [12–16], giving social support [17, 18] and helping with lifestyle change [19, 20]. Furthermore, research on persuasive technology [21] and affective computing [22] is providing technological (partial) solutions for the development of systems and devices able to cope with health issues and awareness. There are many factors to consider when designing products or systems for persuasion. Some people are able to act and be motivated by themselves, while others need to be involved and motivated by others. Motivation is a key element in any system designed to assist users in changing their health behaviour [23].

These kinds of technologies are supposed to persuade user in a logical and reasonable way. If designed well, digital persuasion has way more advantages with respect to the traditional one based on human-human persuasion. Fogg [2] underlines a few advantages of digital persuasion compared to traditional ones and those are related to the fact that the “computers” are much more interesting than people in the long-term persuasion process, they offer more anonymity, and they arrive at the contexts where human beings might not arrive.

Among emerging—persuasive—technologies, the wearable ones have the potential to build motivation by increasing health awareness through timely feedback [24]. A multidisciplinary approach in developing wearable technology based on biology, physiology, nanotechnology, material science and other numerous disciplines is influencing rapid increase both in product and in research development. These devices are often based on sensing technology, communication and persuasion [25].

So far, in the field of health, the wearable technologies have predominately focused on diet and physical activity, such as weight loss, motivating physical activity, maintaining exercise routines and an overall better understanding of an individual’s health. In the commercial sector, one of the earlier more successful devices includes Nike+iPod (nikeplus.com), which employs a sensor in the runner’s shoe and an iPod to keep track of the current pace and distance of a workout. In addition to tracking personal workout statistics, the runner can connect to an online community through the Nike+ website where he/she can track goals, compare running times with others and challenge friends. While Nike+ is designed for the specific activity of running, FitBit (fitbit.com), BodyMedia Fit (body-media.com) and Jawbone UP (jawbone.com) track everyday activities like walking (steps taken), climbing stairs (number of floors) and sleeping (hours and quality of sleep). Much like Nike+, all these wearable devices sync with an e-health application through a wireless base station. Additionally, they provide users with the ability to log individual foods and workouts from a smart phone or computer to track diet and exercise. BodyMedia Fit is geared towards weight loss and is worn as an armband, while FitBit and UP focus on smaller lifestyle changes and are clipped to the waist and worn on the wrist, respectively. Pebble time instead (www.pebble.com/health) automatically tracks when you go to bed, displaying sleep, deep-sleep, and the times when you fall asleep and wake up.

Beside previous examples, wearable systems can be designed with a purpose to provide more control to the users and focus on more health consciousness increasing applications rather than just monitoring because presumably the prevention and health sector is one of the strongest areas of innovation [26].

There are activities and environments for which are required external incentives and motivations. As regards, the objective of our research project was in designing a protective and preventive wearable system that consists basically in monitoring of the user’s physiological parameters (1), environmental monitoring and hazard detecting (2), real-time feedback providing (3) and allowing data transmission.

3. Method

Since when designing wearable technologies it is very important to focus on user’s needs, development of research project was funded on human-centred approach, aimed at meeting not only technological requirements but also and especially user’s needs and meaningful experience.

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Value of wearables is not in having a device that is carried on or held but in its possibility to be worn and integrated in everyday life and activities. A wearable device is not supposed to create the barrier between the wearer and outer world; thus, it needs to have a certain aesthetical quality and be approached as a part of clothing in order to achieve requirements of wearing it everywhere, by everyone and anytime [27]. Despite the fact that commercial wearable devices have recently become more common, up till now there are only few products from this category that satisfy all requirements related to users' needs.

User doesn't really understand the advantages of wearing such devices because often these devices are perceived as uncomfortable and alien to users. This occurs especially when the requirements referring to the formal and ergonomic characteristics are not well accomplished well as adaptability and adhesion to the body and dimensions of the housing [28]. There are different theoretical definitions about comfort, but all of them embrace the concept of creating harmony between the individual and environment and avoiding unpleasantness on all levels of existence. Any good design should consider both a user's need—as in this case is the comfort and body anatomic—and also the aspiration—which would be the designer's know-how. In this way it is possible to design devices that meet both perceptual needs and needs related to wearability of the user [29].

The word "wearability" literally means ability to wear and concerns the physical shape of wearables and their active relationship with the human form. The target is to define the correct/pleasant interaction between the human body and the wearable object by trying to figure out a flexible shape without interfering with human daily activity [30].

Applying human-centred approach in designing means digging in worker's behaviour, perception, working environment and generally social aspects of the work. This does not exclude identifying of product's technical requirements and issues related to wearable technologies. Merging these two in designing process makes possible the achievement of an appropriate design solution both from the point of technological adeptness and general comfort related to wearability [31].

In the development of the new wearable system, authors had to take into account the product language and the correct pleasant interaction between the product and the user but also to design for motivation. Indeed, authors found important emphasising the factor of influencing more responsible users' behaviour towards their health conditions through the method of personal and environmental monitoring. Introducing the technology and technological solutions in this context is a way to provide objective data to the user and raise awareness and motivation.

When designing devices for persuasion, there is also a high demand on the way the feedback is transmitted to the user. For example, the reason why health awareness is accomplished with this kind of devices or applications is because it is in the real time—the gap between action and information (feedback) is denied [24].

For some applications, there is the necessity to create a real-time feedback. If we need a device to persuade on longer periods, feedback out of the context is a valid consideration. One of the often-used methods for creating persuasive technologies is personalisation. Personalised products are more likely to be accepted by the users. Designing personalised product does not have to be realistically addressed to a single person, but that it gives a feeling of being personal [2].

In the following paragraphs, the authors show the design process applied in this research project and development that consists in few phases: (1) the Empathise phase based on design thinking approach and user centred; (2) the Define phase where the project brief was imposed; (3) the Ideation phase in which concepts were developed, followed by the concept evaluation; (4) the Developing phase that is the development of the chosen concept and finally (5) the testing phase to figure out if the new wearable system satisfies user demands and project objective.

3.1. Participants

For the user analysis, the choice of the proper participants was relevant. We decided to choose workers of coating plants. This choice is strategic for the project execution because workers of this environment are highly exposed to the inhalation of several damaging agents (volatile organic components, organic dust, chemical contaminants, paints, varnishes) that cause respiratory disease. Our research activity was supported by Anver (Associazione Italiana Verniciatura) in finding three SMEs available for participating in the user analysis and observation and helping us understand how the process of painting is being executed, who and how is performing this activity and what are the general conditions, rules and norms in coating plants. Three companies with less than twenty employees specialised in finishing and lacquering of metals, polymers, wood and steel were chosen.

3.2. Identifying the users and general problematics

In order to understand the users and what their activity actually consists of we proceeded with organising the user sessions in all three companies. Sessions consisted of two phases: (1) observation; (2) semi-structured interviews. Observation was focused on identifying characteristics of the working activity performed by the worker, his/her behaviour and usage of PPE. Semi-structured interviews were done both with workers to understand the level of perception about the risk and what they find as motivating or demotivating about wearing the PPE, and employers with a purpose to understand how the question about providing and wearing the PPE in this kind of environment is regulated, and in both cases we wanted to understand whether they are positive about introducing advanced technology based on monitoring in their ambit. In this session, all 20 workers were engaged in the period between December 2015 and January 2016. The user session was essential for this research because it was necessary to get to know the users well, their behaviour, if their activity is supposed to take place in coating cabin and with an aspiration system or not and typology of PPE that they are provided. Findings about the PPE show that the workers are generally provided with two different types of masks: (1) Disposable Protective Mask (with a small valve that helps the respiration) and (2) Reusable Half Mask with carbon filters (solid or liquid particles gas and vapour); the selection of these is certainly dependent on technical and chemical parameters such as: Typology of coating, Typology of pollution, Density of Coating Powder. The mask has its expiry date and it is dependent on its typology. Disposable masks last one day and have to be immediately thrown away, while the reusable ones have temporary bodies and filters that are interchangeable and last no more than 1 month. The filter expiring frequency is not dictated only by the hours of wearing but also whether it was protected in the box or exposed

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long time in the environment without being used. Reusable mask should be placed in a protected place and closed when not used.

From 1 h observation (**Figure 1**), it was observed that the workers are wearing PPE only occasionally when there is a presence of overspray that is mostly present in complex geometry painting. These findings brought us to the conclusion that the decision of wearing the PPE and the frequency of wearing it is strongly dependent on subjective perception (principally olfactory or visual).

Even though not all companies have the same equipment and typology of the activity, helpful conclusions were brought from both phases of user analysis. Observation phase results were reinforced with those gathered from interviews which confirmed all our doubts. The Interviews were organised under a few topics: Working activity and protective equipment; Mask's aesthetic and comfort; Safety perception; Personal devices and executed with ten workers (four from the first, four from the second and two from the third company).

All interviewees stated that the decision about wearing the mask is autonomous and personal and that the mask is stored in a drawer when not used. Since the decision of wearing the mask is personal, it is based on the subjective feeling of the worker, or rather on olfaction perception. This causes sparse wearing of the mask that considers time that does not exceed 1.5 h per day. The level of odour presence and overspray is dependent both on the geometry of painted piece and on efficacy of aspiration system. Workers do not believe that the PPE is not useful; they also know that they are suggested to wear it, but they simply do not perceive well the situations for which and for how long it is necessary to wear it.

Beside low comprehension about PPE usage due different factors, workers consider that the mask is uncomfortable because it is too rigid, not enough breathable space and laces for regulations are rather bothering due to being too tight. Workers suggested that the application of new materials and particular attention in designing details may increase wearability and comfort of the mask. Moreover, we wanted to investigate also the safety perception of workers, where only 8 of 20 claimed to be aware of it and understood that the risk comes from the hazards. Additional information that we obtained confirm that according to workers protection level of the mask is good and that they are positive about having information both about personal health parameters and environmental ones that may consider implementation of sensors and advanced technology. With regard to this, workers were delighted about the idea of integration of sensor in

Figure 1. Workers in a cabin.

the mask, wearable device equipped with a sensor able to detect breathing and heart rate parameters and provide information through a Mobile App. Moreover, they would like to know when it is necessary to wear the mask (hazardous condition). They would like to know about daily data (environment and personal health) but also seasonal ones [32–37].

3.3. Delineating project requirements

Results gathered from the user analysis showed a few facts that are very important for project development: (1) Workers prefer not to wear the mask because the environment is not perceived as dangerous, except in some cases where the smell of paint is too evident. (2) Another reason that is influencing sparse wearing of mask is that workers state that generally the mask is uncomfortable. (3) Beside being pessimistic towards existing PPE, workers claimed that they would like to know more about their health condition, activity and working environment. There are some characteristics of the working activity that are to be respected when designing for these users, such as moving easily, having a good and vide visibility, sweating less and maintaining concentration. Thus, the most important factor for the workers was *comfort*.

Related to previously described points, design requirements were defined in the following way: (1) Form has to respond to the anatomical characteristics of the users, considering dimensions that are supposed to remain relatively small; (2) Apply materials that are breathable, anti-allergic and light; (3) Consider to provide filtered air (mask) and (4) Design the device, portable preferably, able to monitor, sense and eventually alert the user.

Making hypothesis about the potential appearance of the monitoring system, we must consider the possibility of designing a small portable device or apparel, or even integrate both. It seems like the only possibility to protect respiration is in the form of mask but integrating sensor inside it and its modus operandi may have different application possibilities. Information provided to the worker should be simple and comprehensive in order to gain motivation and reduce frustration factor. The principal tasks and requirements for designing wearable system were imposed with the intention to raise motivation about wearing PPE in workers by exploiting persuasive technologies, which also considered in improving comfort and providing real-time information about those that can be defined work-related risks, as in this case air quality and personal health condition.

3.4. Ideation phase and focus group

The objectives enhancing the user's consciousness and providing better comfort considered designing the wearable system based on requirements able to satisfy these needs. Related to this were suggested a few strategies as those that consider creating the natural interaction language between the user and device funded on comprehension and engagement able to influence motivation and perception related to personal health. For this purpose, three concepts were generated and each of these was approached by following imposed requirements and design brief regarding materials and technology (soft technology, smart textiles, electronics, etc.). These concepts were studied trough Mock-ups and as a system rather than separate parts (see **Figure 2**).

Among all the elements of the system, the Protective Mask was the most diversified one not only on a technological level but also on a formal level; the general idea was to introduce padded fabric instead of rubber material in order to increase comfort and provide more transpiration between skin and mask and perhaps introduce a new mode of use. Beside these design requirements, the mask was supposed to contain temperature and humidity sensor for human-presence detection. Based on these three concepts for the mask that were generated, the first concept represents familiar architecture of the protective mask with a rigid central part and soft structure around the face. Here the proposed improvement is in the material that is in contact with a face that is designed to be in spacer textile. The mode of use is as in traditional masks with standard regulation laces. Beside the rigid part in front of the nose is provided the space for sensor mounting. Second concept is principally focused on suggesting completely new mode of use that is using a lateral Velcro® closing of the mask body and regulation of laces with a small rotating wheel which makes mask regulation more immediate without a need of taking it off. Here the biggest part of the mask is designed in spacer fabric, leaving rigid part for sensor and filter mounting. The spacer is taught to be coupled with a polymeric membrane in order to isolate from outer hazard agents. The third concept puts major focus on the comfort and here we are proposing a mask completely made in thermoformed laminated spacer textile. The idea is to exploit the process of fabric thermoforming, its possibilities to create the space for sensor and filter cartridges mounting. Besides making the structure lighter and providing more comfort, the filter cartridge mounting facilitation by creating the slide-in system was also thought of here.

For Electronic Nose Device, three solutions based on different visual interactions—graphical form of the information—were generated. The information about air quality is communicated in the following way: (1) *Concept 2:* very simple with two phases of communication that consider only turning on and alarm; (2) *Concept 1:* more complex solution based on three phases that are turning on, warning and alarm; (3) and the last one—*Concept 3*—where there are also three phases as turning, warning and alarm but shaped in the form of a face expressing the emotions from happiness to sadness. All devices combine vibration and LED response. Different modes of use were studied for each device from the point of general wearability (harmony with the human body) that considers putting on and taking off the device and visibility of the feedback due to its position on the clothes or body (see **Figure 2**). Hypothesis about the mode of use of device was based also on the sensitiveness of the body part because beside the visibility of the feedback it is also important that the user feels vibration. Concepts propose the device be positioned in the zone of abdomen in particular arms and chest or making a more flexible form that can adjust to

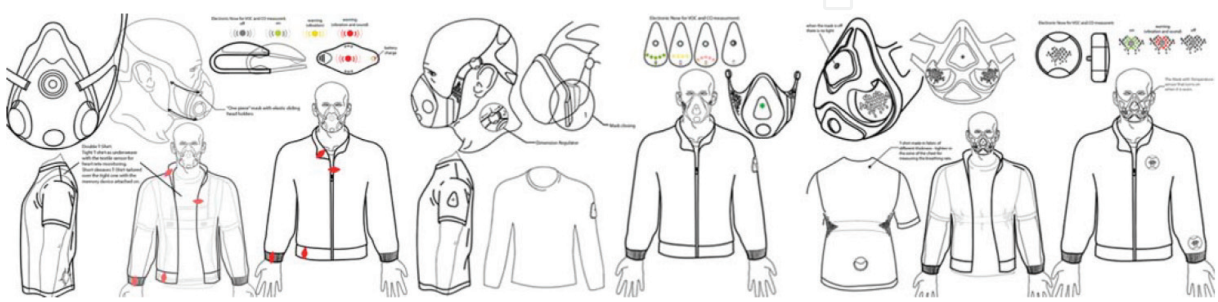

Figure 2. Three concepts of the system.

any part of the clothes. The first concept (see **Figure 2** on left) proposes a flexible clip that can be put anywhere from the T-shirt to the pockets of pants, that can fit to any kind of working uniform. The feedback for this device is in the form of LED that is blinking as alarm passes through four LED colours. Second and third concept (see **Figure 2** on right) are thought to be positioned and fixed on the T-shirt by a push button in order to take it off when the uniform has to be washed. These two are not versatile; they stay always in the same position. Second concept is showing the interface based on mood expression as happy, not so happy and sad as a way to immediate the information related to the air quality that is equal to good, becoming hazardous and hazardous. The last concept is not using specific interface but just colour and vibration. In this case, the device adopts to the protective mask in sense of formal language. Even though the last concept is the one where the system language is empathised, other concepts are also adopting more or less formally to the protective masks next to which they are represented.

Technological principle is the same for each proposed device which consider Volatile Organic Compound (VOC) sensor, vibration motor and RGB LED. All of them have four steps of feedback where the first one indicates ignition signal and then passes to air quality detection that shows three levels: good air quality (green), air starting to be polluted (yellow) and hazardous air (red). Also, the vibration is set on three levels that correspond to LED signal for which when it is yellow the vibration is lower while when red it gets strong. It is possible to stop the alarm by pressing the delay button on device.

Initially, a T-Shirt with textile sensors on the inner part was thought of for the breathing and heart rate measuring. Two solutions were proposed where in the first one T-Shirt was tightened in the zone of chest in order to adhere better and in the second one was proposed undershirt with textile sensors that were supposed to be worn under the clothes or uniform.

Information gathered from the protective mask and electronic nose device are stored in the last part of the system that is the Mobile Application for which are showed three different concepts. Two of these are designed for workers and one for employer (see **Figure 3**). The idea of proposing few solutions, as in the case of Electronic Nose Device, is in the possibility to understand the level of technological and information engagement of users, starting from the basic communication to more complex one. Here were included options of personalisation of the Mobile App profile and various settings related to the working environment for the more complex interaction (*Concept 1*), while for the simple one, only parameters that are results of monitoring are represented (*Concept 2*).

The generated concepts were also realised in form of mock-ups for the user session. Those mock-ups were presented since the early stage of the design development both to engage the user in design process, understand the overall dimension of the product and evaluate its wearability. Indeed, all of these were tested and evaluated by the users. We wanted to investigate how created concepts satisfy needs of users related to previously mentioned parameters. Objective of the session was defining the solution that will be a starting point for final design development. Workers were invited to evaluate each part of the system, for each concept, on a scale from one to five for different objects' qualities, funded on parameters such as aesthetics, function, comfort, mode of use, comprehension of interaction. User session took a place in the same companies where our analysis started, and it was organised with a group of workers and employers that were wearing and trying all mock-ups after which they were given a

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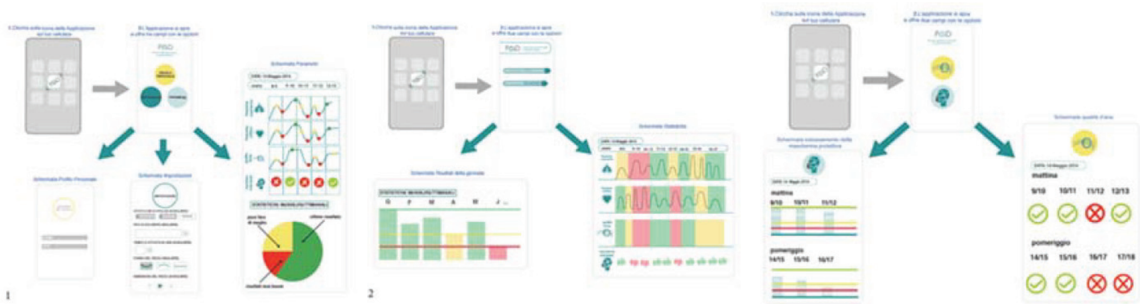

Figure 3. Two concepts of the application for the workers (left); the application for the employer (on the right).

questionnaire to evaluate their experience with each part of the system. During the session, participants' voices were recorded and photos were taken (see **Figure 4**).

During the session workers were able to give general comments and discussed with each other. The difficult part of the session was related to the evaluation of the Mobile App that was provided in form of screen's graphics and it was explained to them step-by-step. Nevertheless, they were also able to validate the App in the given questionnaire. After the session concluded, we gathered results and organised it in order to detect more easily and precisely the main strengths and constrains of proposed concepts. As it was accented previously, the main objective was defining the final concept and the starting point for final design definition. Since concepts proposed for protective mask also integrated application of textile, it was particularly important to have a feedback from workers on whether they liked it or not. **Figure 5** shows the preferences that workers expressed for all concepts.

The Mobile Application that workers preferred was *Concept 2* because they found it the most comprehensive and simple to use. For the mask they indicated in each concept something that was adequate but the most liked one was *Concept 1*. One of the most important parameters for the mask designing was the aspect of comfort and it was evaluated very well for *Concept 1* and *Concept 2*, while *Concept 3* was generally evaluated with lower points. General image of concept evaluation is given in the charts below. The figure does not show results of the smart shirt because it was not appreciated as a solution, so we decided to eliminate the undershirt and leave just a band because it was something that was already familiar to users and considered as more comfortable.

Figure 4. Some pictures from the Focus Group.

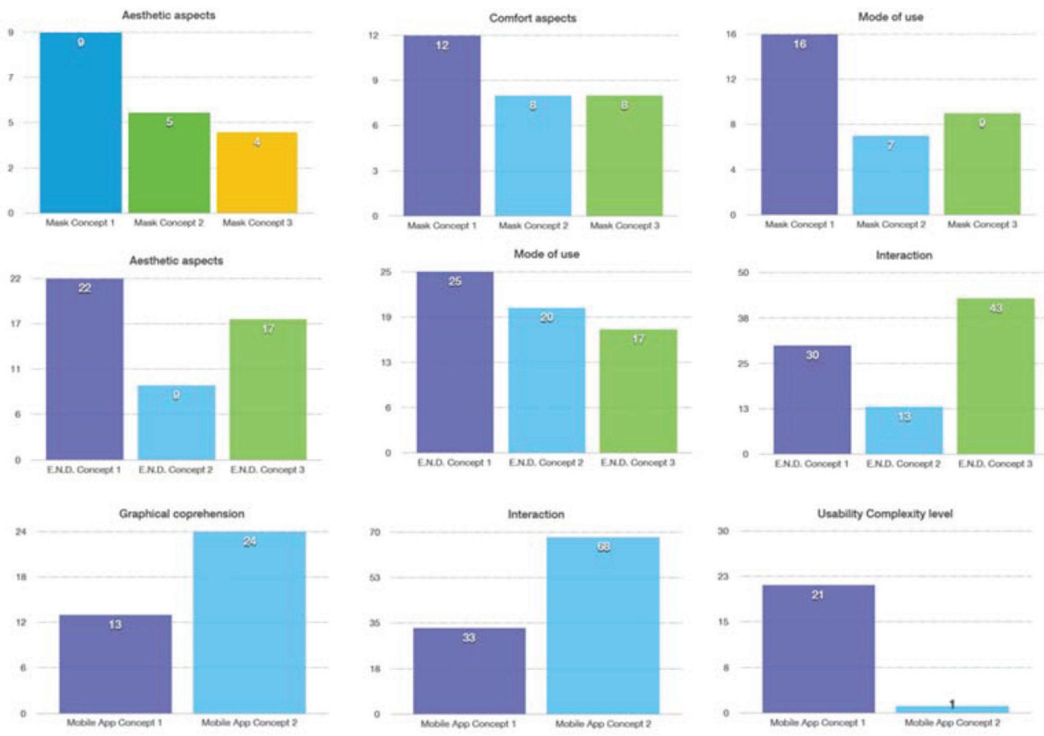

Figure 5. System evaluation.

Concept 1 of Electronic Nose Device was appreciated the most for its mode of use, while *Concept 3* for the mode of interaction by being the more comprehensive one.

About the Mobile App, the most liked one was the *Concept 2*. Mobile App for employers showed approval as being retained as very useful. All workers were positive on wearing the more comfortable mask regularly and being informed about the air quality. These factors may help not only in personal protection but also in controlling the ventilation and aspiration system, considering the employers' plants. After studying new forms, functions and communication, we came up with reviewing the previous concept and created the mask with new formal features, with an outer shell in spacer textile and filters made in thermoformed non-woven textile with a purpose to make the mask lighter. Electronic Nose Device gained a simpler form with a flexible silicon clip. Since the Mobile App was very comprehensible to the users, we maintained the same concept and added the App for employer based on showing the results about the air quality in time and percentage of mask wearing during the day. Since the data about the mask wearing are strictly personal, employers cannot see who is not wearing it but have a general image about the mask wearing expressed in percentage scale.

Once we defined these details and developed new prototypes (**Figure 6**), we organised another focus group session with users after which they approved the final concept and showed rather positive about a possibility to have this kind of devices.

3.5. Developing phase

Further, we proceeded with engineering parts and the prototype of the system (**Figure 7**) which brought us to reviewing again some parts of the project. In particular, we intervened on the Electronic Nose Device design. For the reason of comfort and versatility that we want to obtain, the form of device changed and the form of the graphical feedback as well. We simplified even more the product by creating the abstract graphical representation that excluded the facial expression as a communication and maintained colours because both culturally and perceptually it communicates desired information. The new system consists of a Smart Personal Protective Reusable Mask, a wearable alert device called Electronic Nose Device, a Chest Band t and a Mobile Application.

In order to encourage workers to wear the Protective Mask, its re-design followed the user requirements about aesthetic and wearability. Hereafter, we can see a comparison between the traditional mask and our new design (**Figure 8**).

In the traditional mask, the parts in direct contact with the user's face are made in rubber that causes the mask to be uncomfortable and not worn regularly by the workers. In our new product, the rubber is substituted by a thermoformed spacer textile padded with soft foam. Spacer textile has a structure that is forming exactly to the face and its property to be transpired has the value of preventing from sweating even during the summer days. The Spacer textile chosen for this application has smooth external surface that is very pleasant in contact with skin. Since the spacer textile has a smooth surface, there was necessity to create more friction between the skin and the material surface. This was resolved by printing the silicon pattern in the zone of nose, chin and cheekbone. The layer of the silicon pattern is so thin that it is almost imperceptible, but it is giving enough adherence and friction. Workers were indeed very positive about the idea to replace traditional materials with textile.

Figure 6. System refinement.

Figure 7. New wearable system prototype.

Figure 8. Comparison between traditional mask and new design.

In our re-design, the thermoformed fabric has been chosen for two specific parts (both grey in the image): the part that adheres between the mask's body and the user's face and the laces staying around the user's head. In our intention, in addition to improving the wearability of the mask, the thermoformed fabric will also reduce the risk of skin irritation.

The laces around the head are traditionally manufactured in plastic with strong edges while we decided to use the thermoformed fabric because it is softer and smoother even in contact with the head. Moreover, we used non-woven thermoformed fabric for the filters that are then welded to the mask's base. This choice was aimed at decreasing the mask's weight reducing the use of plastic pieces. The mask is equipped with a temperature and humidity sensor aimed at monitoring the user 's breath (humidity and respiration frequency) but also to check if the mask is worn or not: if the mask comes in contact with the face, the sensor automatically detects the human temperature, or rather presence, and this information goes to Mobile App. User has a real-time feedback about the quality of the air in coating plant trough the Electronic Nose Device. This function is executed with a sensor that is giving objective data about pollution, which are not perceivable by the human nose. The sensor used for Electronic Nose Device (USM-MEMS-VOC) monitors the level of VOCs. While sensing the environment, the Electronic Nose gives three different feedback to the user: (1) green LED on: the sensor is operative and the air contains an acceptable VOCs' level; (2) yellow LED on and low vibration: the level of VOC is starting to exceed acceptable value; (3) red LED on and strong vibration: VOCs concentration in the air is risky for the user health (**Figure 9**).

The real-time feedback alerts the user when there is an urgent need to wear the Protective Mask. This might be the first step in increasing the benefits of wearing the mask regularly. Indeed, in the third-use case, if the user properly feels the vibration, he/she should press the button on the Electronic Nose and wear the mask. Therefore, the nose stops vibrating but in the meanwhile the air quality parameters are constantly monitored and transmitted to the Mobile Application via Bluetooth. Finally, the Chest Band (provided by the Company Comftech) monitors through the working day the user's breathing frequency. It is a textile band sensor that is worn under the T-Shirt (**Figure 10**).

Breathing frequency values are transmitted to Mobile Application to let the user be aware about his/her health every time (when he wears or not the mask). The Mobile Application is a storage of the system; it collects and organises data from the device, mask and chest band. The

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Mobile Application is based on simple graphical representation of three parameters that are comparable in time: breathing rate, air quality (related to the level of VOC) and mask-wearing frequency. Application provides the worker with a complete image of the condition at the working place and frequency of his/her mask wearing and possibility to compare these data in sense of understanding whether the mask was worn when the air was hazard and how physiological parameters were respect to this event. Mobile application was designed to organise data on daily basis and provide weekly and monthly statistics as a sort of archive. Statistical data are intended to increase the visible benefits in wearing the Protective Mask: the worker can see the health progress made thanks to the wearing of the mask. Indeed, he/she will realise (see following section) how his/her breathing frequency improves while wearing the mask. This way, we created a wearable system with several useful features: (1) real-time sensing of the environment; (2) monitor the user respiration giving feedback useful to increase awareness about personal health; (3) 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

Figure 9. Electronic nose device feedback.

Figure 10. Chest band and its configuration.

personal equipment are “static” products. We instead developed an interactive system made up of “dynamic” products empowered with sensors and technology.

3.6. Testing phase

The testing of the prototype was framed into two phases: Phase 1: The observation of the Practical Use of the System in two steps: (1) the workers were asked to wear the chest band and then to use the electronic nose for 30 min, this was useful to figure out if they understood how the electronic nose works; (2) They wore both the electronic nose and the mask; Phase 2: An unstructured Interview aimed at understanding: (1) Comfort and wearability of the overall system (Mask and Nose); (2) System Feedback Understanding; (3) Application Understanding; and (4) P_O_D_ Efficacy. The user session was organised as a general observation coupled with sensor data collected in the working space and was carried out in May of 2017 on five workers. For the test, we choose the first one of the three companies analysed during the first user session because we met a very open-minded owner willing to innovate, experiment and to use the results of the project afterwards. Moreover, the workers of this company were the most collaborative and proactive ones.

Firstly, workers were given the prototypes and they were supposed to work with it on. This user session had two objectives. The first one was testing the products with users and the second was to understand the accuracy of the system in sense of monitoring data, both vital and environmental. In the image below, we can see the users in the painting cabin wearing the prototype (**Figure 11**).

At the same time, while workers were performing their activity we were controlling the parameters about the breathing rate and air quality through Apps on the mobile phone. Electronic part of the product showed as accurate, the quality of the air was changing respect to the presence of the overspray and distance from the object that is painted. It was giving a feedback to the user in real-time and the user found it quite comprehensive. The same is for breathing data; they were changing with respect to the level of presence of overspray and whether the mask was on or off. In the image below are shown the results obtained from air quality measurement and heart and breathing parameters (**Figure 12**).

After the observation in Coating Plant, users were engaged through an unstructured interview where they explained what they experienced while working with a P.O.D. system and if we succeeded in improving the wearability of the system. Workers were rather positive about the new mask; they appreciated the application of spacer textile instead of rubber and said that they were willing to wear it. They also appreciated Electronic Nose Device very much; the workers appreciated the possibility to wear it a versatile way: on the pants’ pocket, on the shirt’s collar, on the shirt’s sleeves; the feedback and its general functioning was clear to them. They did not complain about the comfort of chest band, they found it unobtrusive and easy to use. In the end, they were given the Mobile App simulation to try to use it. Workers found it simple to use, the complexity of the app was proportional to their level of operating with this kind of medium and the graphical representation was immediate for them. Moreover, the employer showed interest in the system, but in particular he found very useful Electronic Nose Device and his Mobile App. Finally, observing the system as a whole, we can conclude that the improvement of the mask

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Figure 11. Users engaged in the final testing of the product.

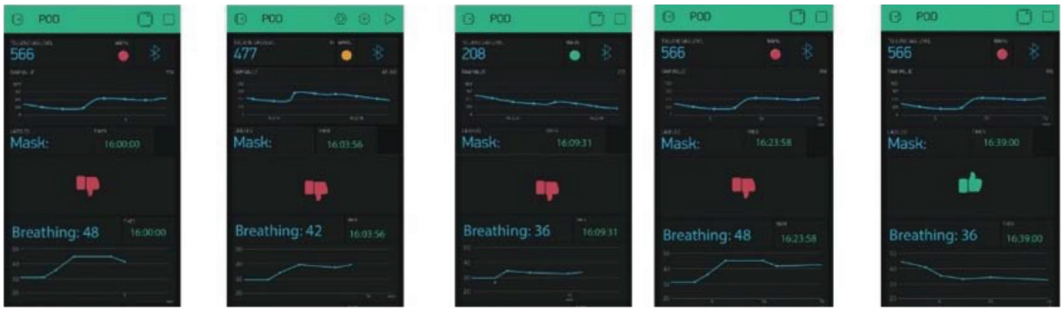

Figure 12. Simulation measurement of air quality and vital parameters.

respect to the user's needs defined in the beginning of the project, raised the benefits related to the wearing of the mask and by this the willingness of workers. Giving a real-time feedback showed that when there is the visible input about the risk, they remember to wear the mask and their belief in the air quality changes. Having the data in Mobile App certainly impact motivation of workers by showing the progress of wearing the mask in time.

4. Conclusions and further development

A high number of respiratory diseases related to working environment are mostly present in sectors such as agriculture, manufacturing and transportation. Data coming from INAIL show that the manufacturing sector is the most dangerous among these where just in 2014 were detected 5172 cases. The best method of prevention and general increment of health in this case is wearing of PPEs. Results from our user analysis, obtained from three coating plants, approve that the workers are not willing to wear the mask. What we suggested as a solution to this problem was to encourage the workers to wear PPE by raising work-related risk awareness which they often undertake. This was thought to be executed by exploitation of persuasive technologies. Persuasive technologies may be defined as a tool able to influence or indeed change people's attitudes and behaviours [2]. Fogg [21] believes that successful products, the ones user will continue to use after the novelty, will be those that incorporate "hot triggers" to help people change their behaviours for the better. Behavioural Model developed by Fogg, (FBM), is funded on the thought that any target behaviour occurs only if the person has sufficient motivation, ability and effective trigger; and these are supposed to occur at the same time. This model suggests that the motivation is a trigger of an action or behaviour. Motivation as a characteristic of human action is stimulating to act and demonstrate one kind of behaviour and not the other. It is not always oriented towards positive but also towards negative or not acting decision. Motivation is certainly the reason of our actions and it shapes behaviour with respect to what is desired or how much willingness we have for acting. We use our motives as inner factors that are directing towards action [23]. In the field of working environment, we faced the behaviour problem related to the responsibility and the willingness of wearing the protective equipment. We had few questions to answer: Could an individual approach like self-motivation generate consciousness about risks the workers are at? How the sense of hazards and injuries could let them understand health risks and change behaviour? To answer these questions, we proposed a Wearable System able to address the main problem of "motivating" by improving the comfort and wearability of the system and raising self-awareness about health issues. Besides the theoretical literature, the analysis on the direct user brought to the development of a system composed of four devices: a smart mask, two devices that are monitoring physiological parameters and one dedicated to the environmental monitoring of working place and real time alerting about the level of hazards in the surrounding (i.e. visual and tactile feedback when the environment is hazardous). The system suggested in this research consists of three wearable devices and Mobile Application. In such a system, the motivation starts from a new mask (equipped with temperature sensor) redesigned with attention to the wearability and comfort, evaluated as high by the workers, while the Electronic Nose Device maintains the motivation of the user through information, or alert, about air quality (gas, CO_2), and even though the user generally does not want to wear the mask, he/she will be more encouraged to do it by changing the perception about the risk and by this also the behaviour. Beside environmental monitoring and alerting, also physiological parameters have a purpose to inform the user about the health condition when exposed and not to hazards, and here Chest Band has an important role. Data gathered from all devices are organised in mobile app and are communicated through simple graphical information: if the mask is worn or not; the level of air quality; and the quality of breathing. Seeing how these parameters are related will impact one's self-awareness and increase consciousness. This kind of system operates during the time, by giving knowledge and—as a result of it—conscious behaviour, that on long distances improves health condition. The results of the performed user test are promising: they gave us a first confirmation that the designed system could be an acceptable and effective proposal. Nevertheless, more research is required to demonstrate both that the behaviour change by workers will last longer than the duration of an observation session and that the improved mask's wearability will be enough also after several hours and days of usage. We are currently working on the research project follow-up in collaboration with a SME based in the northern area of Milan that develops and sells respiratory protection products; the collaboration is aimed at improving the system. The company is interested in testing the entire system on a wider population of users not only in Italy but also in Spain and Netherlands where it has other companies' branches. The company also wants to test it in different working environments such as body shops, agriculture, and restoration and is very committed to translating the prototyped system into a commercial product.

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Conflict of interest

In accordance with our ethical obligation as researchers, we declare that we have no financial, commercial, legal or professional relationship with other organisations, or with the people working with them, that could influence our research.

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