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A method to visualize and quantify "aerosols" of outward leakage around the perimeter of barrier masks

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ABSTRACT

Due to the SARS-CoV-2 pandemic, several strategies have been proposed to reduce its transmission, from social distancing, regularly disinfecting items and hands, and wearing barrier masks. Guidelines and standardization propose certain tests for the filtration of the masks, or visual inspections to check the materials. However, no standards exist to tests the outward leakage through the face seal perimeter of the masks. Therefore, the aim of this study was to develop a method to visualize and quantify respiratory droplets, simulated by 'mist', exhaled by a mask wearer.

A setup was developed with fluorescent ink, UV lights, background subtraction, to highlight the mist and its footage. Mist was quantified with a software, and one-way ANOVAs and t-tests were conducted on the means, to assess the reliability of the method. The results of the statistical tests suggest that the method is reliable to visualize and quantify the mist.

INTRODUCTION

SARS-CoV-2, the virus responsible for COVID-19, has a size of 120 nm diameter (Morawska et al., 2020). It tends to be embedded in water drops or droplets, which depending on the size, can be categorized as aerosols. Exhaling, singing, sneezing, coughing, and talking will cause the release of the respiratory droplets, which can contain the virus (Chen, Zhang, Wei, Yen, & Li, 2020) . Although the load of virus contained in droplets, and the amount of virus needed for a person to develop COVID-19 is still not well known, it has been suggested that masks can reduce the risk of spread of such droplets, in addition to social distancing to avoid direct projectiles (Buonanno, Morawska, & Stabile, 2020; Morawska et al., 2020) . Cases in which infections via aerosol have been documented have occurred in Germany and the USA (Mitze, Kosfeld, Rode, & Wälde, 2020; Van Dyke et al., 2020).

Wearing a facemask has become obligatory in most countries as it has shown to reduce contagion (Chu et al., 2020). Barrier masks are designed as a preventive measure to protect people surrounding the wearer, in case the wearer is a carrier of the virus. This type of mask has been encouraged to be worn by the public over medical masks, and companies have capitalized on the public's need to wear them to put on the market a wide range of masks.

Official guidelines exist in certain countries specifying different types of tests to be performed on masks, such as visual inspections (tears, looseness, fit, etc.), filtration, resistance material for daily wear, and filter breathing resistance. However, tests specific to the performance and leakage through the face seal perimeter of the mask or fit tests have not been specified in guidelines yet.

Current standards and guidelines, whether international or national, seem to be limited in the type of tests to be performed in masks in order to assess their quality and performance. AFNOR (AFNOR, 2020), NEN (NEN, 2020) and CEN (CEN, 2020) suggest that consumers should pay attention to the fit, by observing a tightness in the perimeter of the mask in contact with the skin. In Ireland, SWiFT (SWiFT, 2020) proposes that masks should be tested in different head types, sizes, and ages, to ensure the best fit. Visual tests are also encouraged, by checking from scratches, proper elastic and attachment, adequacy of materials, and comfort of seams and nose pieces. Similarly, guidelines from other countries also propose that manufacturers carry visual inspection of the materials, ensuring that there are no defects, tears, detachments, or deformations of the materials. The guidelines also propose that consumers should perform the same type of visual inspection before donning (AFNOR, 2020; CEN, 2020; NEN, 2020).

Some studies have attempted to visualize outward leakages in several ways. Typically, visualization of flows and turbulences has been done with several techniques in different fields (Smits, 2012). These can be divided into three main categories: bubble visualization, dye visualization, and smoke visualization.

Bubble visualization requires a generator from a probe, proper illumination, typically with angled backlighting (Sabatino, Praisner, Smith, & Seal, 2012). Bubbles can be photographed and processed with quantitative instrumentation, such as Laser Doppler Anemometry or Particle Image Velocimetry (PIV), in order to provide quantitative data of the flows. The technique has recently been used to visualize infections aerosols indoors (Bluyssen, Ortiz, & Zhang, 2021).

Dye visualizations have typically been used to study flows in water. Typical dyes used have been food coloring, milk, ink, fluorescent ink, fluorescein, or laundry brightener (Smits, 2012). While smoke visualizations are the typical method for flows in the air. Smoke can be of different sources, glycol, water vapor, or titanium tetrachloride. Mask performance has been studied with smoke visualization. Darby et al. (2021) used synthetic aerosol made of NaCl in water from a nebulizer. UV-lights and fluorescent dye was used by Maruyama et al. (2020) to assess droplets dispersal during endoscopy. The same technique was used by Teichert-Filho, Baldasso, Campos, and Gomes (2020) to assess aerosol and droplet dispersal during dental procedures. Other studies used distilled water and glycerin to imitate cough and sneezed aerosols (Verma, Dhanak, & Frankenfield, 2020a, 2020b).

Real droplets expelled by people have also been visualized, mainly with the use of sophisticated equipment, such as backlighting and high speed cameras; in such studies, the flows, turbulences, speeds, and distances traveled are measured (Bourouiba, Dehandschoewercker, & Bush, 2014; Scharfman, Techet, Bush, & Bourouiba, 2016).

Other studies, have also envisaged to quantify outward leakages. This has mainly been done by tracking particles or counting them. Particles from coughed aerosols to assess mask efficacy by producing aerosols of nebulized KCl and collecting it with an Andersen impactor for quantification based on based on the aerodynamic diameter of the particles (Lindsley, Blachere, Law, Beezhold, & Noti, 2020).

PIV has been widely used with combination of tracer particles and smoke (Kähler & Hain, 2020) in order to track and quantify aerosol particles. While particle counting has also been used to detect and count particles based on their size (Wendling, Fabacher, Pébaÿ, Cosperec, & Rochoy, 2021).

As a method of both visualizing and quantifying does not seem to have been developed, at least as a rapid response study or with simple, yet reliable equipment, this study attempted to develop a method for doing so.

Additionally, as mentioned before, no standards or guidelines exist for the assessment of leakage of masks, therefore, the aim of this study is to design a method to visualize and quantify respiratory droplets simulated by 'mist' exhaled by a mask wearer, to assess the outward leakage of barrier masks.

METHODS

A setup was created by simulating the exhalations of a human, by connecting a bellows pump to a Styrofoam manikin head of the size of a male adult. The inside of the head was carved in such a way to duplicate the volume of the respiratory cavities of an average adult head. Fluorescent water mist was produced to visualize the exhalations, with the use of an ultrasonic nebulizer and a combination of nine parts of water with one of fluorescent ink. This mist was produced in a container chamber positioned below the head, which also acted as a build-up chamber for the mist. The chamber was connected to a duct connecting it to the aforementioned bellows pump. For the optimal visualization of the fluorescent mist, the space was equipped with six ultraviolet lights and the surfaces were covered with black paper and plastic foil, so as to avoid any reflections and to increase the contrast between the mist and the background. Additionally, during the experiments, all lights, except for the UV lights, were turned off. The location of the experiments was the Experience Room of the SenseLab, in Delft. A camera was placed at a distance of 2.5 meters away from the head, at two positions, the side and the front, in order to have footage of the leaked mist from two perspectives. Footage was taken in a time-lapse mode, by taking a picture every two seconds, so a total of 60 pictures per test were obtained. The camera used was a GoPro Hero 8 with a wide-angle lens of 130 degrees. Figure 1 shows the setup of the experiment.

Figure 1*: Setup in the Experience Room with Styrofoam head, UV lights, and black backgrounds.*

A total of fourteen different masks were chosen to be tested, varying from characteristics typically found in commonly available face masks. These features were: materials, number of layers, woven vs non-woven materials, cheek flaps, and filter type.

Every mask was tested a total of four times and footage of the leaked mist was taken twice from the side and twice from the front. The procedure for testing each mask followed the next steps: turn on camera. Turn on UV lights, turn off ambient lights, put mask on the manikin head, turn on ultrasonic nebulizer, build up mist in chamber for 1 minute, start recording footage, turn on bellows pump and count two minutes of exhalations, turn off pump, stop nebulizer. The procedure was repeated for each of the masks.

In order to analyze the leaked mist, a series of processes were performed. First, the resulting images from the time lapse were processed with the FFmpeg software, with which background subtraction was performed (figure 2). Background subtraction is a method that compare a sequence of images with a static background, in which the static background is removed, only highlighting the moving objects, which in this case is the leaked mist.

The images with subtracted background were then analyzed with Image Color Summarized v.0.77; which gives descriptive statistics of the colors of the image. In this study, two percentages were produced: that of the subtracted background and that of the mist. This was done with the pictures taken in the 40th, 50th, 60th,

Figure 2 Same picture in 50th second, as raw footage and after background subtraction.

70th, 80th, and 90th seconds of the tests, as it is when the mist had reached a stable state.

From those color percentages, means of the percentages were calculated as well as sums of the percentages. In order to validate the sturdiness of the test, the mist percentages were compared between the two runs of the same camera position. Next, independent sample t-tests and one way ANOVA's were conducted with SPSS v. 26.

More specifically, the ANOVAs were performed in order to determine whether statistically significant differences exist between the two test runs of each side, per side, between the 40th and 90th seconds. The t-tests were performed to determine if the means of the two runs per side were statistically the same.

RESULTS & DISCUSSION

The results, which are presented in Ortiz and Bluyssen (2021), suggest that statistically significant differences exist between the four tests, and also between the two means of the side and front test runs. Also, differences were shown between the 14 tested masks for the front view and in three of the 14 from the side view. As a result, for those particular masks it can be hypothesized that their means are different.

Further tests should also take into account different head sizes, to emulate different genders, ages, or ethnicities, as well as facial hair.

CONCLUSION

The proposed method could be a valuable addition to the aforementioned tests in order to ensure the better protection and information to the consumers. This technique allows to visualize and quantify mist that leaks out in a cost-effective manner, while enabling to see the routes of leakage and improvement points for different mask types.

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