Analysis of the Ergonomic and Functional Indicators of Protective UV-C Masks for Work in Contaminated Environments

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***Abstract*—Usage of UV-C light is an economical and environmentally friendly technology for surface and air disinfection, but it's used as stationary facilities in public buildings. This article presents an innovative product of a personal protection mask that uses this technology. It allows users to work in pathogen contaminated environment without affecting the aspiration. The developed design not only sterilizes the inhaled and exhalated air, but also provides ease of use, functional reliability and comfort fit across diverse facial topologies. The design is physically prototyped and experimental research was done on mixed male and female target group. The survey approved that the developed protective UV-C mask has good ergonomics, provides a secure facial seal and maintains an unobstructed field of view.**

Keywords— ergonomic survey, personal protective mask, sterilization, UV-C mask.

I. State of the Problem

From 2020 to 2022 the world was in the midst of ongoing public health challenges due to the COVID-19 virus The use of ultraviolet germicidal irradiation (UVGI) has emerged as a powerful, reliable and environmentally friendly alternative of chemicals used for disinfection. [1][2][3][4]. This prompt a development of innovative design of protective mask that uses UVGI technology for working in contaminated areas. Adopting the UVGI technology to inactivate SARS-CoV-2 requires personal protective equipment to be able to provide radiation exposure between 20 J/m^2 and 37 J/m^2 for 90% lethal dose (LD90). [5] [6] [7] [8] [9],

The innovative design of transparent face mask with integrated goggles, incorporating all necessary components to achieve the irradiance dose for LD90, was developed. However, it was challenging to define an optimal magnitude and direction of contact pressure to properly fit on user's face topology, during wearing. Another critical parameter is the weight distribution of the mask, an aspect for which there is a notable gap in the existing literature. Furthermore, a review of the literature reveals a lack of systematized information regarding the ergonomics and comfort of face mask use. Based on these observations, the aim of this study was established: to analyze the ergonomic and functional parameters of protective UVC masks and goggles designed for use in contaminated environments.

The sterilization process occurs within the integrated UV-C filter module, which is affixed to the transparent elastic face mask via a ring-shaped lip seal. Ambient air enters the module through a circular inlet, which can be equipped with a discrete particle filter for dust protection. Within the module, the air follows a controlled zigzag pathway, maximizing exposure to high-intensity UV-C irradiation emitted by the integrated LED source, as shown on Fig. 2. This extended exposure duration ensures that the required LD90 sterilization efficacy is achieved without imposing significant respiratory resistance. The internal geometry of the module is specifically designed to function as a UV-C barrier, effectively preventing unintended exposure to the user.

II. Methodology

The developed design presented in Fig. 1 shows a general view of the mask and its location on the user's head.

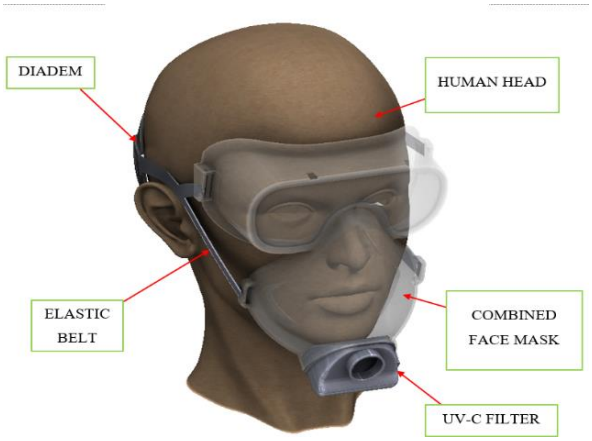

Fig. 1: Composition and architecture of a UV mask

When operating the mask at low temperatures and when conditions are suitable for moisture condensation, a drainage channel is placed in the rear part. This ensures the outflow of any moisture present from the inside of the respirator part.

The design of the UV-C filter module prioritizes ease of cleaning and maintenance, with these considerations integrated from the conceptual stage. To facilitate cleaning, the use of fasteners has been eliminated; instead, all components are securely held together by a ring-shaped lip on the elastic section of the mask.

The module housing consists of two interlocking halves and incorporates a UV-C transparent separator that isolates the airflow from the electronic components, shown in Fig.3. This separator ensures that the PCB with soldered UV-C LEDs and other electronic components, along with the

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battery power source, remain protected from exhalated air exposure.

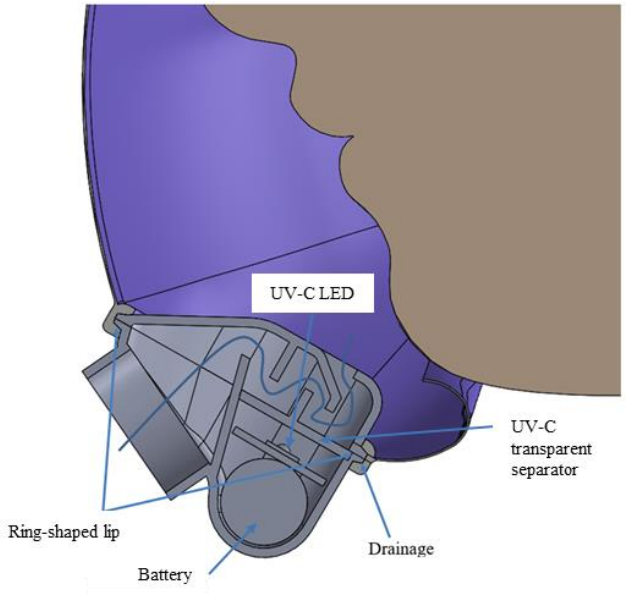

Fig. 2: UV-C air sterilization

A deformable cover, indicated in red, is integrated into the housing design to safeguard the USB-C charging port and the on/off switch from contamination. This cover maintains a secure seal and can be displaced to allow battery recharging via a USB Type-C cable after a discharge cycle. Alternatively, the UV-C LED module can be detached from the mask, allowing for direct battery replacement with a fully charged unit.

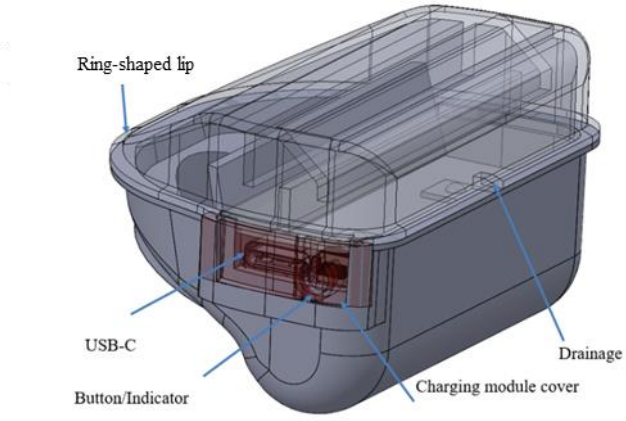

Fig. 3: UV-C filter module

To assess the ergonomic and functional performance of protective UV-C masks designed for use in contaminated environments, a study incorporating both quantitative and qualitative indicators was conducted.

First, quantitative indicators were analyzed, including weight balance, battery discharge rate, and the operating time of UV-C LED per full battery charge. These parameters were evaluated using objective numerical values.

Second, qualitative indicators were assessed, encompassing ease of donning and doffing, visual field coverage, ease of battery replacement, ergonomic fit, wearing comfort and convenience of cleaning. Given the inherently subjective nature of these factors, a survey-based study was conducted among students to obtain an objective, statistically valid evaluation of the UV-C mask's usability in contaminated environments.

III. Study of Quantitative Indicators

Maintaining a balanced mass distribution was prioritized during the design phase to enhance user comfort. The achieved weight of the UV-C filter module is approximately 60 g, which directly contributes to ergonomic performance and minimizes discomfort during prolonged use. A detailed weight distribution analysis is presented in Table 1.

Table 1: Weight balance

Component	Weight, [g]
Top cover	6.4
Bottom cover	8.8
UV-C transparent separator	5.3
PCB + UV-C LED	7
Battery	30
TOTAL	57,5

The module is powered by a 5000 mAh Li-ion battery. The UV-C LED, along with its driver circuit, requires a power of 2180 mW. Based on this power requirement, the system achieves an estimated continuous operating time of approximately 8 hours per full battery charge.

IV. Study of Qualitative Indicators

This study involved the production of a batch of physical prototypes of the face mask, shown in Fig.4, using industrial injection moulding technology, optimized for medium-volume manufacturing. The primary objective was to validate the mask's ability to accommodate diverse facial topologies while ensuring user comfort and functionality.

Fig. 4: Assembled mask

The evaluation focused on several key qualitative indicators, including ease of donning and doffing, visual field coverage, ease of battery replacement, ergonomic fit, wearing comfort, cleaning convenience, and user notification features. To systematically assess these aspects, a structured survey was developed, encompassing both the overall mask design and the influence of the integrated UV-C sterilization module. The survey aimed to generate a representative sample of user feedback regarding the mask's functionality and design.

Each participant tested the protective mask by securing it to their face, with sealing ensured via an elastic band. The study included 16 participants (14 male and 2 female), who provided feedback through a structured questionnaire. In addition to answering predefined questions, participants

were given an open-response section to offer subjective insights.

The questionnaire is divided into two parts, the first one related to ergonomics, and the second one to the impact of the added UV-C sterilization module:

• Are you satisfied with the ergonomic features?
• How do you rate the seal of the mask on your face?
• How do you rate the comfort when wearing the protective mask on your face?
• How do you rate the added sterilizing UV-C module?
• How do you rate the comfort when inhaling/exhaling?
• How do you rate the field of view when using the mask?

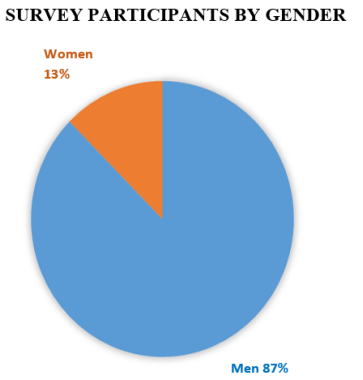

Fig. 5: Gender distribution of the survey participants

The answers to the questions are presented in the following figures, with the graphs presented together for all respondents, including men and women. The results are presented as a percentage of the answers.

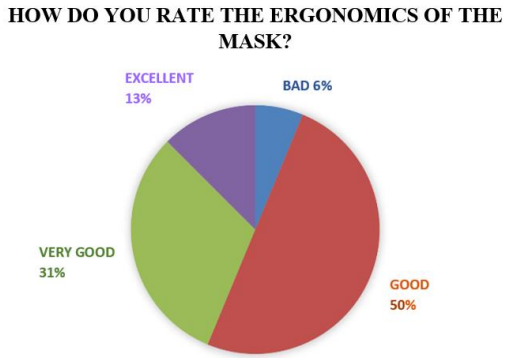

Fig. 6: Question No. 1 of the survey

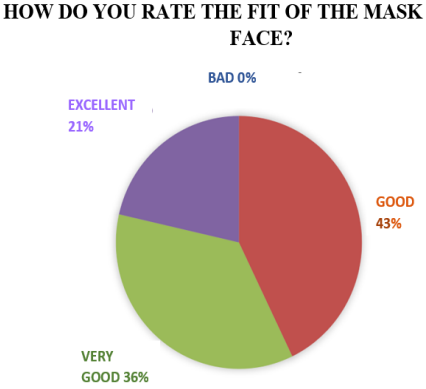

Fig. 7: Question No. 2 of the survey

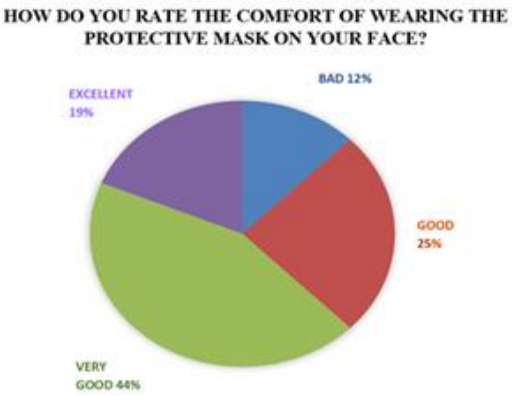

Fig. 8: Question No. 3 of the survey

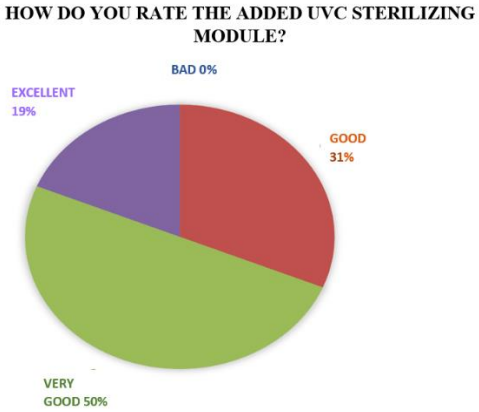

Fig. 9: Question No. 4 of the survey

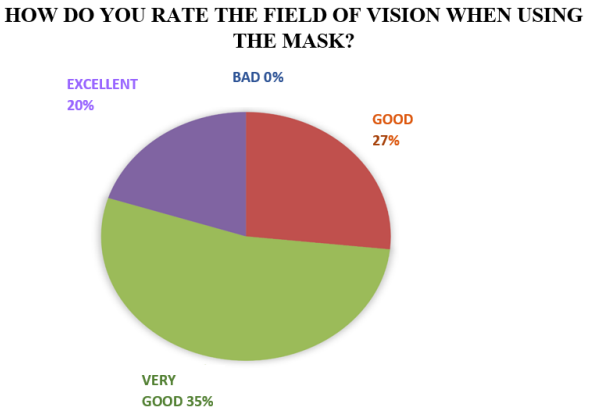

Fig. 10: Question No. 5 of the survey

Question No. 6 "How do you generally evaluate the presented protective mask with a built-in protective function?" from the survey is an open question in which participants can share their impressions about the protective mask. The feedback received is presented in points:

It is good! The elastic could be a little more comfortable;
Add a second link;
It is excellent.;
The quality is excellent! It is made perfectly!;
Excellent.;
Pretty good, but the elastic comes off easily.;
Good idea.;

V. Analysis of the results

Based on the conducted study, a representative evaluation of the design and ergonomics of the protective face mask has been established.

The overall ergonomic evaluation yielded highly positive results, as illustrated in the accompanying graphs. However, it was observed that the average rating among female participants was below the overall average. Further analysis, combined with direct feedback from respondents, identified the need for improvements in the elastic band, as it did not provide an adequate facial seal for female users. This concern was particularly noted in response to Question No. 6 of the survey, which addressed potential design modifications. Based on these insights, an additional improvement in this component is recommended to enhance comfort performance across diverse facial structures.

Regarding the integration of the UV-C sterilization module, the majority of respondents indicated that it does not impede respiratory function or restrict the field of vision. This confirms that the geometric design of the module effectively maintains user comfort and functionality.

The developed geometric concept eliminates the need for specialized fasteners to connect the module to the mask body, ensuring high functional performance. The module can be securely attached and removed manually without tools, particularly in the flexible section of the mask, allowing for convenient insertion and removal during cleaning.

A validation survey conducted with a final design prototype, manufactured using an injection mould tool, confirmed that most participants rated the mask as having excellent ergonomic properties, particularly in terms of ease of placement, wearing comfort, contact adhesion, and applied force distribution.

VI. Conclusions

The evaluation of the protective face mask with an integrated UV-C sterilization module confirms its high ergonomic and functional performance. An innovative arrangement of the elements and an optimized airflow organization during inhalation and exhalation have been successfully defined, ensuring no breathing resistance while maintaining effective sterilization. A virtual prototype of the design for protective mask with integrated UV-C LEDs has been developed and verified, achieving an optimal weight balance that enhances user comfort.

The mask demonstrates good ergonomics, providing a secure facial seal while maintaining an unobstructed field of view, ensuring usability in various working conditions. The design also incorporates an efficient cleaning concept, with a modular structure that enables quick disassembly and maintenance, ensuring high hygiene standards.

The achieved quantitative parameters of the design, including a total weight of approximately 60 grams and an estimated continuous operating time of approximately 8 hours per full battery charge, are also significant, contributing to the overall functionality and long-term usability of the device.

Overall, the study validates the mask's effectiveness in providing comfort, ease of use, and functional reliability in contaminated environments, with targeted improvements suggested to enhance fit across diverse facial topologies.

Acknowledgements

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