Received: 31 August 2020 | Revised: 24 May 2021 | Accepted: 6 August 2021

DOI: 10.1002/hfm.20934

WILEY

A study on usability and design parameters in face mask: Concept design of UVW face mask for COVID-19 protection

Bahram Ipaki[1] | **Zahra Merrikhpour**[2] | **Mohammad S. Taheri Rizi**[3] | **Saman Torkashvand**[4]

[1]Faculty of Design, Tabriz Islamic Art University, Tabriz, Iran

[2]Industrial Design Department, Art and Architecture Faculty, Bu-Ali Sina University, Hamadan, Iran

[3]Department of Industrial Design, University of Tehran, Tehran, Iran

[4]School of Medicine, Hamadan University of Medical Sciences, Hamadan, Iran

Correspondence

Bahram Ipaki, Faculty of Design, Tabriz Islamic Art University, 37CV+FW8 Nowbar, Tabriz 51376-53515, East Azerbaijan Province, Iran.
Email: ipakdesign@gmail.com

Abstract

The aim of this study is to investigate the usability of conventional masks to prevent the transmission of coronavirus 2019 (COVID-19) and subsequently design the proposed concept of the mask to reduce leakage and increase efficiency. Acute respiratory syndrome COVID-19 is spreading around the world and can be transmitted from one person with COVID-19 to another through personal contact and breathing. Improper design of current masks can lead to virus transmission. One hundred fifteen users participated in the study using a simple random sampling method in which N95–FFP2 face mask and surgery face mask usability tests were chosen as the most widely used face masks in Iranian people with an online usability questionnaire. Data were analyzed by SPSS. The results showed that the usability of the N95–FFP2 face mask with a total average of 4.46 and a surgical mask with a total average of 3.35 cannot be considered acceptable. Anthropometric and formal changes in people's faces and improper design of the face masks used make it necessary to review the mask redesign measures to increase the prevention of pathogens. In this study, new parameters for face mask design are proposed. Thirty different types of jaws have been considered with the help of CorelDRAW software, along with ideas for optimal mask design with UVW mask concept to be accessed by manufacturers around the world.

KEYWORDS

adaptability, design parameters, face anthropometry, personal protective equipment, usability testing and evaluation

1 | INTRODUCTION

The disease of coronavirus 2019 (COVID-19) is caused by acute respiratory syndrome first seen in 2019 in Wuhan, China (Ren et al., 2020). COVID-19 is an acute respiratory virus that is similar to MERS-CoV in that it causes high persistence in the air at low temperatures (Bernard Stoecklin et al., 2020; Pyankov et al., 2018). The COVID-19 is a relatively greasy virus that can stay in the air for up to 3 h and remains on smooth or polished surfaces compared to textured surfaces. Also, if a coronavirus-contracted person is breathing in one place, he can spread the coronavirus up to a radius of 2.5 m when a mask is not used. If people gather, the rate of spread of infectious diseases will increase. Breathing is one of the most common ways of transmitting coronavirus disease. Since hospitals also have limited capacity to admit patients, the best approach to prevent the spread of COVID-19, research has shown, is to avoid admitting patients contracted with other routine respiratory viruses such as influenza to hospitals (Centor & Fisman, 2020; Dai et al., 2020; Klompas, 2020).

Researchers have long suggested that masks should be used to prevent respiratory infections, such as the flu, to limit the release of

viral droplets. To combat coronavirus, the importance of mask production has been highlighted (Leung et al., 2020). It is recommended to use N95–FFP2 and N95–FFP3 face masks to prevent, control, and manage the COVID-19 (Cascella et al., 2020). We consider a mask as important medical equipment in strengthening this approach and reducing the problems caused by it. The World Health Organization stresses the use and production of masks to deal with COVID-19 and also on their usability, correct use, and efficiency to reduce the risk of transmission and prevent the creation of a false sense of security. Because the face mask can limit some face-to-face contact that usually includes coughing, abnormal breathing, and droplets containing microorganisms, which is one of the major sources of virus spread (World Health Organization, 2020). Designing is one of the most common ways to improve healthcare needs. Choosing a design approach based on design position can determine the ultimate quality of a product design or medical service. Human factors are one of the main disciplines in design for health (Branaghan et al., 2020). The patient-oriented design focuses on preventing or controlling a disease known to be of great importance in work-oriented approaches (Reis et al., 2011). The usability test is a one-step design experiment in which designers technically evaluate the background of a product to grasp a better design (Geisen & Romano Bergstrom, 2017; Rosson & Carroll, 2002). In these usability tests, a user is tested in interaction with a product to determine the efficiency of the product (Lee & Ha, 2019). This is done with the aim of discovering gaps and product problems that are an inseparable part of user-centered design. However, in the patient-centered design approach, all activities move to prevent the development of the disease in a normal user and prevent the recurrence of the disease (Reis et al., 2011).

1.1 | Research background

One of the main symptoms of the COVID-19 is shortness of breath (Patel et al., 2020). Therefore, people infected with COVID-19, as a personal duty to maintain the health of their family, the public, and public health, in addition to controlling the outflow of the virus from their lungs to the outside environment, should be able to breathe easily, demanding that the design of masks plays a special and helpful role. It has been reported that the effectiveness of all personal protective equipment for the healthcare staff of COVID-19-infected patients is low (Ng et al., 2020). Some personal protective equipment in healthcare comprises masks, gloves, shoes, safety clothing, goggles, and hats. It can be concluded that the optimal design of care equipment is of great importance and will be effective in preventing the transmission of this virus. COVID-19 is also very dangerous for the elderly (Applegate & Ouslander, 2020). In this way, considering that the shape of the jaw and face of this group of people is quite different from the youths, the design of the mask becomes more challenging. A study by Chughtai et al. (2020) highlights that there are differences in countries' health policies for using FFP2 and FFP3 masks to prevent COVID-19 (Chughtai et al., 2020). Yet, it is not clear what this mask does for the COVID-19. Zhou et al. (2018) worked on the design of the new N95 mask, the results of which showed that the filter of that mask is very effective in preventing the entry of influenza viruses (Zhou et al., 2018). While for air conditioning, they used a smart fan for inhaling and exhaling, so possibly the production process is longer and the final manufacturing costs are higher. Also, in the 2016 study by Zhang et al., the presence of a fan was shown to be useful for reducing the accumulated concentration of carbon dioxide and temperature control (Zhang et al., 2016). But the interesting point is that technically, the entry and exit of air requires a rotating fan on both sides, which makes it difficult to breathe or exhale due to the presence of a fan with a propeller on one side. In this way, if the fan makes it easy to exhale, air will pass around the mask in the inhaling mode. So again, we have a problem with usability. In the case of the N95 mask without filters and the surgery mask, the research conducted by Tang et al. (2009) showed that a lot of air passes through the face masks and never does filtering involve a large part of the air (Tang et al., 2009).

The study by Radonovich et al. (2019) also did not show a significant difference in comparing the effectiveness of the N95 mask with the surgical mask in preventing the risk of catching the flu (Radonovich et al., 2019). While there are various models of N95 masks. In this way, it can be admitted that the N95 masks can not be more effective or efficient than surgical masks. Because surgical masks have a simpler structure and are more easily and quickly produced, thus being also cheaper. However, according to other research, these face masks have inferior usability.

In a 2020 study by Suen et al., cup and flat-fold platforms of N95 masks (Figure 1) were compared with each other in terms of usability, with the information from 104 nursing students. Cup and flat-fold are two platforms of current face masks by duck and circular form design used in different countries. The results showed these masks are not suitable for continuous protection because of leakage and entry of the unexpected amount of air and it is necessary to increase the observance and ensure the respiratory protection of the users in the redesign and development of the design (Suen et al., 2020). In a 2015 study by Cho et al., the rate of air passage during respiration was observed when moving the head in three different models of 3M-N95 face masks used in best form a performance was 46% during exhale (Cho et al., 2015). Also, in 2010, Bowen's research on mask resistance to the swine flu virus (H1N1), severe respiratory distress syndrome (SARS), and pathogenic avian influenza (HPAI) emphasized the protection of surgical masks and unfiltered masks than N95–FFP3 was much lower (Bowen, 2010). O'Kelly et al. (2021) also reported low accuracy in fit-testing of KN95, N95, surgical, and cloth face masks, and considered redesign based on facial proportions necessary for better protection (O'Kelly et al., 2021).

1.2 | Objective problems

In general, in the anatomy of the head and face, mainly female and child users have more delicate jaws. However, we see the lack of this type of mask in the design of existing examples, and many of the

FIGURE 1 Left to right: N95-Cup 3M, N95-Flat Fold 3M, and N95-Flat Fold Nanofiber

most commonly used masks are designed in one size, posing a serious problem, which is to adapt the design of the mask to the anthropometry of different jaws. To do this, we must first know what is the status of common and widely used masks.

1.3 | The purpose statements

The effects, complications, and mortality of COVID-19 and other epidemics are spreading, and designers need to work with doctors, nurses, and other researchers in this area and make the best of their ability to inhibit or control the virus. If a mask is used to ensure its effectiveness and prevent the risk of transmitting the virus, the designed mask should be very effective in empowering the users to have more ability to prevent pandemics. This study, by examining the usability of N95 and surgical face masks, seeks to suggest an optimal design of the mask to prevent the spread of respiratory viruses with a focus on preventing the spread of COVID-19. N95 and surgical face masks are widely used and have not been evaluated yet by some usability criteria in recent studies. Assessment in this study can lead to recognize the problems and provide design solutions to them.

2 | PROCEEDINGS

This is a dual process study that includes quantitative and qualitative cases in such a way that the links created between qualitative and quantitative issues lead to the output of the conceptual face mask design. To evaluate the existing masks, the usability test will be used to identify the existing gaps and move toward the proposed design to solve those problems.

3 | STUDY 1: METHODS

3.1 | Participants

Participants in this study included 115 Iranian men and women who were chosen by convenience sampling through an invitation on social media. One of the reasons for the inability to determine the target group in terms of age and gender differences was the problem of interaction with different users and also the impossibility of direct access to them due to coronavirus disease. Since in the selected topic, the focus is on the design of the product itself rather than the physiological issues, the inequality of the number of male and female participants in this study is low, and on the contrary, the users were selected randomly. Also, their age difference and segregation are descriptive only due to the dispersion and similarity of the participants and have no effect on the results. Details of participants' data are shown in Table 1.

3.2 | Data collection

A questionnaire was created in Google Docs and then the questionnaire link was sent to the participants on WhatsApp, Telegram, Instagram, and also emails. Before answering the questionnaire, participants were reassured that their information will remain confidential and that they were free to answer questions, that these permissions were approved by them. Also, with this method, users in different cities of Iran could answer the usability questions. The importance of the issue is that in usability questions, even if at least three users are dissatisfied with the performance of a product, it means that the product has a problem in terms of usability. Because this is the user's need. In this study, the utility of the N95–FFP2 face mask and the surgical face mask shown in Figure 2 were investigated. These samples are the most common types of masks used in

TABLE 1 Demographic information of participants

Demographic categories	Frequency		Valid percentage		Difference
	Case 1	Case 2	Case 1	Case 2	
Gender					
Male	25	35	21/7	30/4	−10
Female	15	40	13	34/9	−15
Age					
+18	41	74	35/6	64/4	−33
Sensitivity	11	12	27/4	16	

Note: Case 1 represents N95–FFP2 masks and Case 2 represents surgical masks.

Iran among the general public, which can be easily prepared and have been widely used in the corona pandemic. In Iran, every user uses these masks at least several times. High cost is one of the main reasons for not trying other standard masks. The image of both masks was placed in an online questionnaire so that each user could choose an option, and they were also asked to select the sample they most used.

3.3 | Usability questionnaire

The usability test of face masks can show us what features of design create problems for users. In this study, we designed eight usability questions with a Likert scale based on five independent variables. The Likert scale comprised scores: *Inefficient*, 1; *Very Poor*, 2; *Poor*, 3; *Average*, 4; *Acceptable*, 5; *Very Good*, 6; and *Excellent*, 7, which are defined according to users' feedback and then their effective average is announced. Table 2 shows the designed questions, and Table 3 describes the research variables. Table 2 shows the relationship between the questions and the variables as each of the variables is described. Some variables are adjusted to the research of Radonovich et al. (2019) and Suen et al. (2020), and others are determined by reviewing the research background. Radonovich et al. (2019) stated that there is no difference between N95 and medical masks in terms of safety from the influenza virus family. This problem showed us that there are low-safety and low-fitted features in N95 and medical face masks. Also, the study of Suen et al. (2020) has confirmed the Radonovich et al. (2019) studies about fit testing and effectless of that to high-safety for breathing systems (Radonovich et al., 2019; Suen et al., 2020).

TABLE 2 Usability testing questionnaire

Q1. I feel comfortable while using this mask
Q2. Using the mask, I do not have any concern of contaminated air entering in
Q3. Mask is fitted well on the face, nose, chin, and jaw
Q4. The air does not pass the mask edges while inhaling and exhaling
Q5. While speaking I am sure the mask is on the right position
Q6. Rotating left and right, I am sure the mask is fitted properly
Q7. Moving head up and down, I am sure the mask is fitted properly
Q8. While wearing mask, I feel safe against virus penetration

3.4 | Data processing

Due to the fact that not all parameters are well-supported in the latest study questionnaires on mask usability, the design of a developed and standardized questionnaire becomes very important. Approval and standardization of the questionnaire will also be important. For this reason, the face validity and reliability of the questionnaire were first checked by six faculty members in the fields of two ergonomists, two industrial designers, and two physicians. Then, after collecting the data using Cronbach's alpha, their internal consistency and reliability were quantified and the final confirmation was reached, as mentioned in Table 4. According to the results of Cronbach's alpha ($\alpha > .7$), the questionnaire can be repeated by other researchers. This result shows that the designed questionnaire has standard capabilities. After filtering the data, the pure and outdated data were analyzed by SPSS 19 and then their details, such as middle, mean, low limit, and high limit were determined by box and whisker plots. While in standard usability, according to the Likert scale, the acceptable level is at 5, the level at 6 and 7 shows very good and excellent usability.

4 | STUDY 1: FINDINGS

Due to the feature of N95–FFP2 mask in the usability announced 38 users, there is the main design problem is in the areas of safety with the median of 4.5 and average of 3.93, fit-testing with a median of

FIGURE 2 Left: Case 1 (filtered mask N95–FFP2); right: Case 2 (surgery mask)

TABLE 3 Relation between variables and questions

Independent variables	Description	Variables in questions
Comfort	Convenience between using the mask and adapting to different parts of the head	Q1 + Q3
Breathing	Air leakage due to noncompliance with facial anthropometry and easy breathing while using the mask	Q2 + Q4
Fit test	Comfortable placement of mask components on the head and face as well as no air leakage around the mask	Q2 + Q3 + Q4
Unmovable	Do not move the mask over the head and face when talking left, right, up, and down	Q5 + Q6 + Q7
Safety	Feeling safe and not worrying about the entry and exit of polluted and nonpolluted air after wearing the mask	Q2 + Q8

TABLE 4 Cronbach's alpha of research-made questionnaire from this study

Items	Cronbach's α	Std. α	G6(smc)	Average R
All variables	.8511	.8478	0.8693	.4106
Q1 excluded	.8291	.8254	0.8492	.4031
Q2 excluded	.8211	.817	0.841	.3895
Q3 excluded	.8218	.8185	0.8415	.3918
Q4 excluded	.8106	.8073	0.8321	.3744
Q5 excluded	.8259	.8207	0.8288	.3954
Q6 excluded	.8281	.8228	0.8293	.3987
Q7 excluded	.8316	.8278	0.8522	.4071
Q8 excluded	.8853	.8853	0.894	.5245

4.83 and an average of 4.44, and comfort with a median of 4.0 and an average of 4.06. While in the fit-test variables and the safety, the skewness is toward the lower usability. There are fewer breathing problems with a median of 5 and an average of 4.53 and skewness stretching below 5. However, the median and the average in the immovability variable at 5.31 show that acceptable usability. In the field of safety, due to the importance of the user's concern induced by the entry of air around the mask and the subsequent feeling of unsafe against the COVID-19 and its prevention, in this study, this issue was considered as the most important design parameter.

However, the usability of the N95–FFP2 mask with a median of 4.7 and an average of 4.46 is between medium level and acceptable level. Therefore, only the design parameter related to immovability in the N95–FFP2 mask is acceptable and can be implemented on similar products in future designs. Figures 3 and 4 show the independent variables and the usability test results of the surgery face mask expressed by 77 users and N95–FFP2 face mask by 38 users.

In contrast, the surgical mask is not a good option. The main design problems are safety variables with a median of 2.5 and an average of 2.57, breathing condition with a median of 2.5 and an average of 2.97, fit test with a median of 3 and average 3.23, comfort with a median of 3.5, and an average of 3.78, which show minimum usability against coronavirus infection for 75 participants. Also, the results of usability at 3.35 show the average usability and in this regard, it needs to be redesigned. The immovability in the surgical mask with a median of 4.33 and an average of 4.18 does not seem to be a major design problem as in the case of the N95–FFP2 mask and the previous design features can be used to fix the mask on the face in new models. But anthropometric changes create new requirements. According to the results of the review of parameters and capabilities, re-designing the mask is essential.

5 | STUDY 2: METHODS

This part of the study shows an operating anthropometric design process, for which the design must support various anthropometric data. The anthropometric-based design provides good adaptability in wearable equipment (Ipaki, Amirkhizi, & Heidari, in press). Therefore, the modular design approach has been chosen to improve the flexibility in the adaptation by face form so we can cover a variety of face shapes with different dimensions with configurability and different sizes of the mask. The arrangement of the components in the modular design increases adaptability (Meyer & Lehnerd, 1997).

5.1 | Engineering USP

According to the usability results, the most important problem was the inappropriate form and incompatibility of the design pattern of the masks with the anthropometry of different faces and in none of the situations, we saw results in a very good and excellent range. The results showed that changing the pattern design is necessary for greater compatibility. The ease of inhaling and exhaling was also a serious problem so that to solve this problem, an air inlet filter and an air outlet filter should be considered.

According to a 2015 study by Cho et al., the N95 masks cause respiratory problems at 46% which, reviewing minor changes to improve filtering, is the same as the results of the current study. The usability for the breathing variable in the N95–FFP2 model is also associated with deficiencies. So that air conditioning is difficult to do through the filter (Cho et al., 2015). For respiratory protection, Suen et al. (2020) also emphasized the redesign of three types of N95 masks to increase

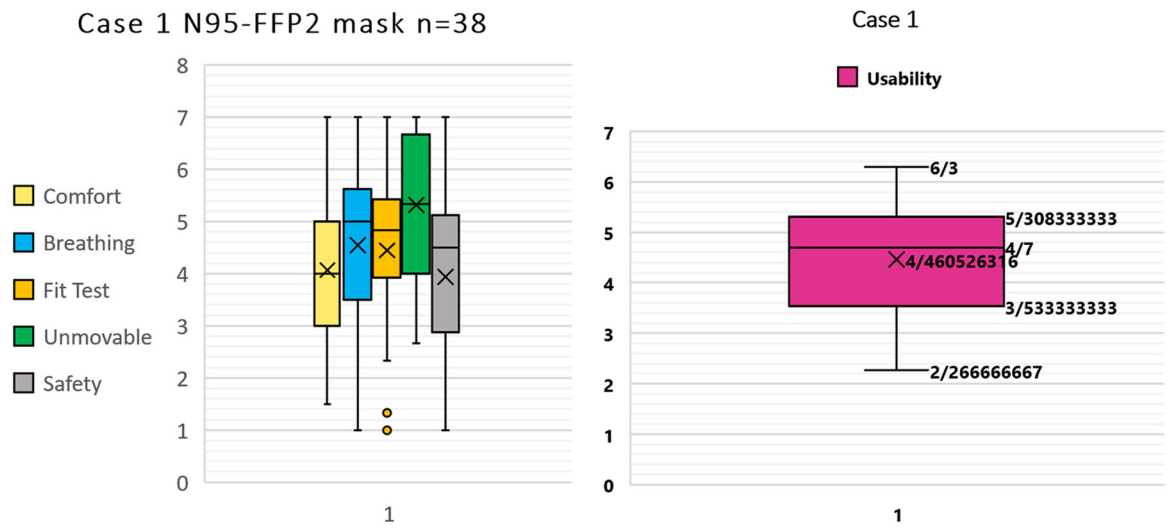

FIGURE 3 The box and whisker diagram and the test results of the applicability of the N95–FFP2 mask

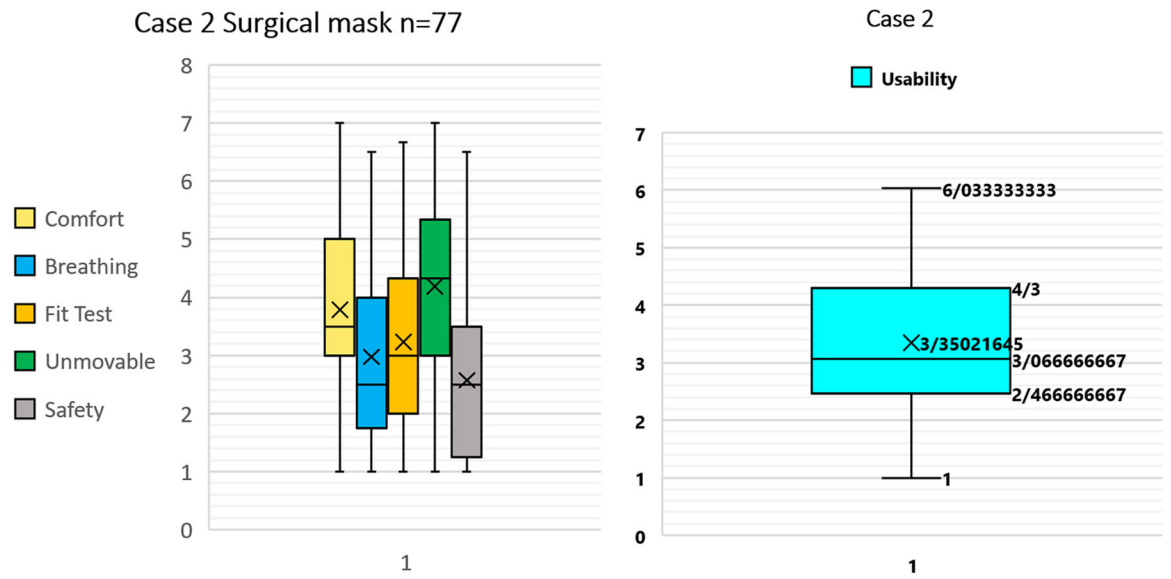

FIGURE 4 The box and whisker diagram and the test results of the applicability of the surgical mask

respiratory safety and eliminate leaks (Suen et al., 2020). Due to the fact that inhaling is more difficult than exhaling, if the user does not need mechanical ventilation, it is appropriate to have a one-way filter. Yet, increasing the number of filters from one to two will increase the possibility of increasing the amount of oxygen in inhaling.

Also, during the COVID-19 pandemic, one of the main problems of face mask use, that is the potential for pollution in the environment and disposable face masks (single-use) are a new environmental challenge that is playing a key role in microplastic pollution (Fadare & Okoffo, 2020; Sangkham, 2020). Recently, the use of reusable masks is expanding because of the expensive price of N95 face masks and the weak usability of surgical face masks in different geographical locations (Shruti et al., 2020). So, reusability and washability is another issue that highly depends on the material used to make the mask.

When using a face mask, the safety of fitting, convenience, and the ability of verbal communication with others depends on the design features (Kirillov et al., 2013). Representing the measurement of the efficiency of the mask shows the importance of controlling air penetration from the distance between the face and the mask in the design. According to various experiments on masks, due to the presence of different anthropometric features in the people's jaws, is observable the leakage around the mask and jaw, as well as around the nose and mouth. The manufacturers must produce masks based on the regulations applied by the World Health Organization (NIOSH) (42 CFR 84.135): Masks should be designed to fit the shapes and sizes of different types of faces in terms of anthropometries (Table 5) (Institute of Medicine et al., 2007). The design of the hat and face mask has led to the collection of extensive anthropometric information related to the head and face. This

TABLE 5 Facial dimension measured in the NIOSH-sponsored Anthrotech study

	Facial dimension	Definition
	Bigonial breadth	The straight-line distance between right and left gonion on the corners of the jaw
	Bitragion subnasale arc	The surface distance between the left and right tragion at the bottom of the nose
	Bitragion chin arc	The surface distance between the left and right tragion across the anterior point of the chin
	Head breadth	The maximum horizontal breadth of the head above the level of the ears
	Menton-sellion length	The distance in the midsagittal plane between the menton at the bottom of the chin and at the deepest point of the nasal root depression
	Nose breadth	The straight-line distance between the right and left on the sides of the nostrils
	Chin	The protruding point on the bottom edge of the chin, along the jaw line

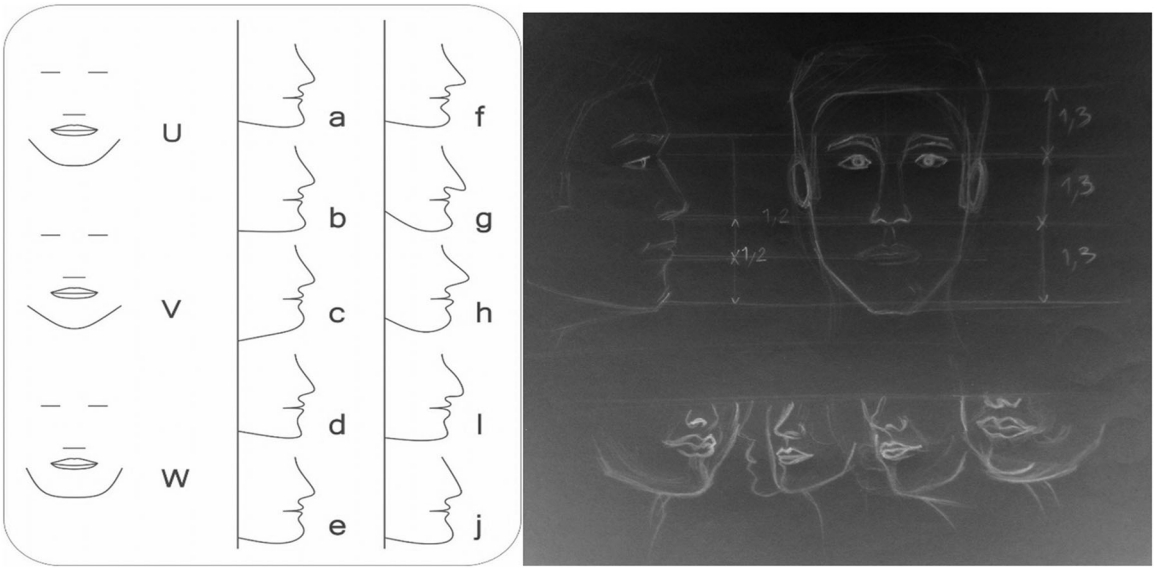

FIGURE 5 Left: the supposed schematic of formal variation of jaw. Right: general scale of golden points in face and jaw variety. *Source*: designed by authors

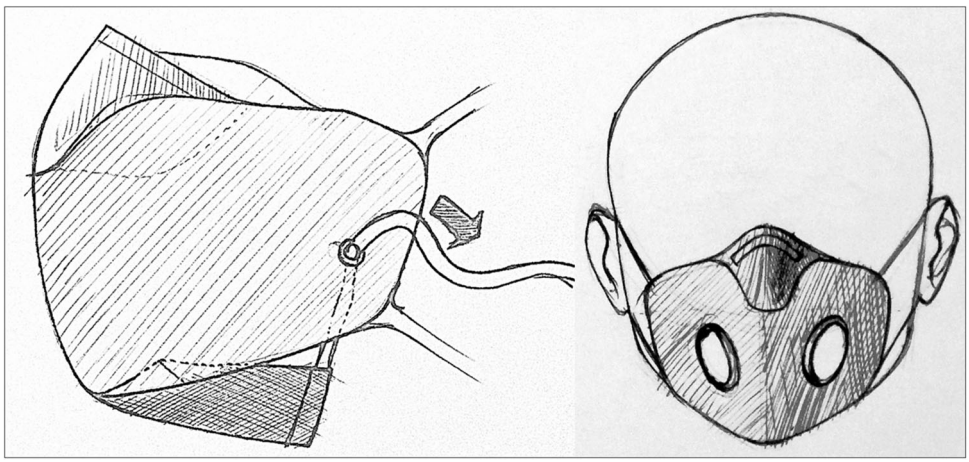

FIGURE 6 The initial sketch of the left side of the mask with the chin adjustment strap and the hook–loop system in the nose section, the concept of the right sketch using two filters and the view facing the main idea. *Source*: design by authors

information will be appropriate to determine the location of the eye, nose, chin, and mouth against protective masks (Pheasant, 1996). Because of the wide range of users, the mandibular morphology, including thickness, width and height, large and small faces, and facial curvature should be considered. Researchers have also found that estimating the average anthropometric dimensions of face length and lip length is not easy compared with other facial dimensions, such as intermediate distance, nasal area, and protrusion.

In the following, according to the findings of the research, to achieve the details of mask design, the design guidelines are formulated. Regarding the necessity of including a filter in the mask to prevent COVID-19, it is vital to specify what the filter and design feature should be. According to research by Zhou et al. (2018), the filters used in N95–FFP3 mask have the ability to filter out the flu virus. Due to the formal similarity of the COVID-19 to influenza and the large size of the human COVID-19 at 98 μg/m compared to the c-type influenza virus with dimensions 149 μg/m, the feature used in the influenza mask can be described in the new design to be effective (Vlasak et al., 1988).

5.2 | UVW face modeling

In this section of the research, considering anthropometric differences, 30 types of jaws have been supposed to avail, designed with the help of CorelDRAW software. To create a sketch of the jaw and face form, a general division of the jaw form was performed by default. This face form division was done in three styles of front-view and 10 styles of side-view according to the general principles of Walter Foster head and face

FIGURE 7 Paper prototype of mask concept UVW (medium fidelity). *Source*: authors' design

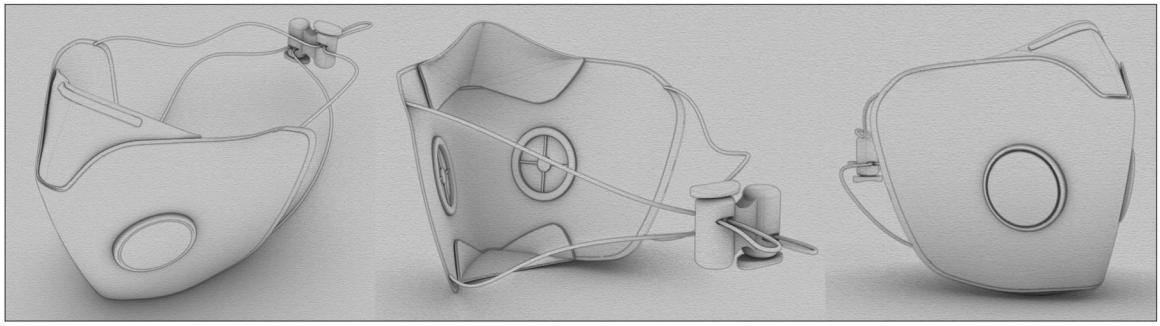

FIGURE 8 Different views and applied components of designed concept with software

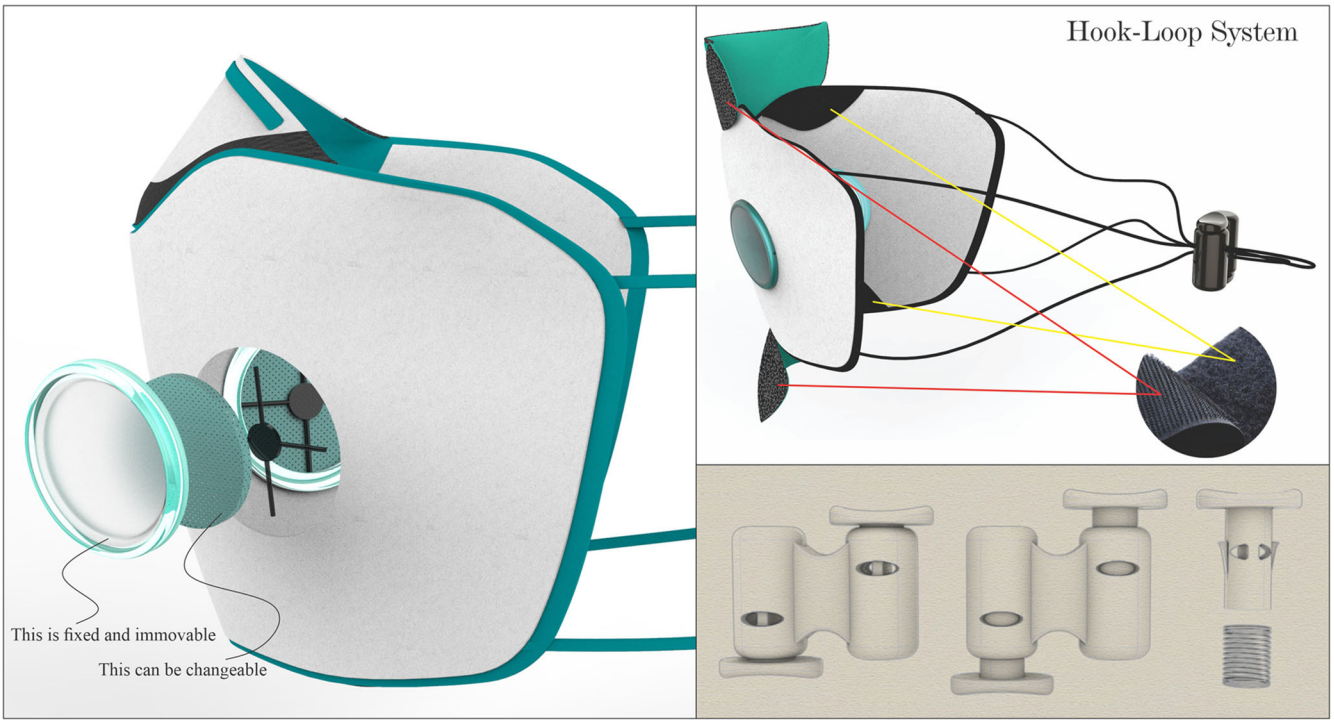

FIGURE 9 Using a hook–loop system to fit the jaw and a two-way locking button to adjust the strap to increase fit. The replaceable filter can be used to estimate the average continuous usability and to add the required number of additional filters in each package. *Source*: authors' design

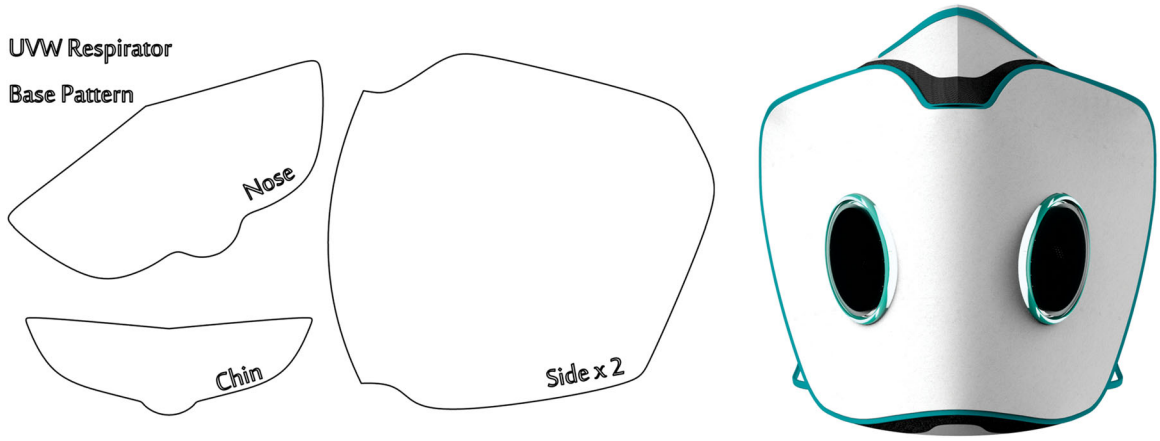

FIGURE 10 Computer rendering of the product with Key Shot software and the basic pattern of the UVW mask concept

drawing in which the way of dividing and arranging particular parts of the face is made in accordance with the shape and elements from adults and children faces (Foster, 1997). In this category, each of the front-view shapes combined with the corresponding side-view shapes created the 30 various models of jaws and face forms. This process has done by observation in which another 10 states were multiplied by each of the UVW jaws, based on which were done the formal design and geometric patterns of the proposed mask. Totally, we take into account 30 different forms of faces summarized in Figure 5. It should be noted that these sketched face platforms almost covering the face form of male and female users and even children.

6 | STUDY 2: FINDINGS

This section reports the result of conceptual design according to the background, instructions, and findings of Study 1. This content describes the operational aspects of the design and each design features seven criteria, which are as follows.

6.1 | Anthropometry and fitting

Due to the huge and diverse range of users, in general, available face masks (surgical and FFP2–N95) have single-size. It is important to note that to increase performance and anthropometry, this design must be produced under NIOSH anthropometric data and in four sizes: XL, L, M, and S. This design has its fundamental differences in terms of more attention to the face anthropometry than other current face masks.

6.2 | Filtering

Air filtering in face masks is the most common vital issue of healthy respirators for the human body. Findings show us that the mask filter must behave as being two numbers. One of them is for inhalation and the other for exhalation, and then that the filters should be replaceable. Also, should be used of two-color design for the back/front of the filter materials in that the user can change the filters by attention to inhalation/exhalation. Filters must be for single-use and after using a mask, they should be immediately changed or disposed of. Afterward, it is necessary to put a number of filters in the mask package for replacement and subsequent use.

6.3 | Hook–loop system

It is important to fit the mask on the face. The hook–loop system in this design makes the features modular and flexible. Meantime, we create more fittings by adaptive design properties from the hook–loop system. In this concept design, we used an adjustable hook–loop system for better adaptation to the user's face. This is something like a shoelace.

6.4 | Strap

The finding showed that the immovability variable of the studied masks has problems and it is 2° away from the excellent state. It is often difficult to close and hold the mask on the face for a long time. Using a suitable strap for the mask can increase its continued use. Here, we designed a two-way locking button to adjust the strap to increase the stability and fitting of the mask on the user's face.

6.5 | Adjustable design

Equitable use and flexible usage are very important principles in universal design. Adjustable design can make these two principles possible to a large extent (Null, 2013). Operational use of this design method can support more users for face masks. Users can have more adaptation in terms of face form and face anthropometry in using the face mask. In the design of the UVW face mask, the straps and pieces

TABLE 6 The advantages and disadvantages of the proposed design

Design criteria	Situation	Reasons
Face form	Satisfaction	Due to the three-piece design with four different sizes
Breathing in	Dissatisfaction	Needs more research and depends on filter design
Breathing out	Dissatisfaction	Needs more research and depends on filter design
Fitting	Satisfaction	Due to the use of hook–loop system and strap for the chin
Unmovable	Satisfaction	Due to the setup on the face and using spring hook for strap
Fixing	Satisfaction	Using adjustable back-strap
Safety	Satisfaction	Neglecting dangerous elements
Establishing speed	Satisfaction	The product is not complex
Using ability	Satisfaction	No specific skill to use, the ordinary user can use it easily
Filtering	Dissatisfaction	It needs more scrutiny but two filters must be used, one for inhalation and the other for exhalation
Changeable filter	Satisfaction	Filter concept is designed to be replaced
Continuous use	Dissatisfaction	Users may become tired of using the mask after a long time
Persistent use	Satisfaction	Washability and filter replacement may be applied until the loss of the main quality such as hook–loop system
Facilitate	Satisfaction	Steps are easy to implement
Anthropometry	Dissatisfaction	Cultural and face frame are different and results can be generalized. Different sizes may help to overcome the problem especially for the youth
Use of glass eye	Satisfaction	Using hook–loop system prevents the accumulation of breath vapor on glass
Special users	Dissatisfaction	Some certain people may not use this product and it is necessary to do more research
Cheap material	Dissatisfaction	Materials are cost-effective
Permanency	Satisfaction	The materials used in the design are easily available in the market
Easy to tasks doing	Satisfaction	Product components are simple
Optimum production	Satisfaction	It is produced at the same speed as the N95 mask
Open–close	Satisfaction	It functions easily to open and close
Washable	Satisfaction	New filter can replace the old one after washing up to four times The hook–loop system is damaged
Learnability to use	Satisfaction	It is necessary to use the guideline and brochure
Anti-allergy material	Sacrifice	This item was not investigated. Some people may be sensitive to…material
Easy assembly	Satisfaction	In this concept, sewing and thermal pressing are done easily in the factory
Structure simplicity	Satisfaction	The components used are known
Ease of manufacturing	Satisfaction	Due to the simple components, production is not complex
Packaging	Dissatisfaction	Packaging is important, the necessary information must be inserted and needs more research
Aesthetics	Satisfaction	Designing product is compatible with the color in medical equipment

on the nose and under the jaw provide the ability to adjust properly. In this way, the user has more freedom of action in the proper use of the mask.

6.6 | Material

We have limitations in this stage of face mask concept design. However, we suggest the linen-cotton composite material for washing and reusability. Because washability by cotton is low and linen material is in low resistance against the virus. But washability by linen is high, and virus resistivity by cotton is high (Xiao et al., 2020). Also, it has been reported that using cotton masks can be more effective in surgical masks if it is used in open environments to prevent the disease (Ho et al., 2020). So, maybe the composition of these materials has the best performance. Some materials that are used for face mask production like nano-fiber, carbonic, cotton-silk, cotton-chiffon, cotton-flannel (Chua et al., 2020) can be replaced with linen-

cotton. Manufacturers must select usable materials for face masks according to the price and accessibility.

6.7 | Manufacturing

Figure 6 is a selection of sketches from a collection of ideas that show the generalities of the design in the early stages. Figure 7 shows a paper prototype made from an idea to show the ability to execute and extract a construction pattern. This physical model is a medium-fidelity prototype. Figure 8 shows images of the computer-aided concept. Figure 9 shows the performance system and the key elements of the mask, which were prepared with the help of Rhino software. Figure 10 shows the computer rendering of the product from the front view, as well as the dominant pattern of the mask.

7 | GENERAL DISCUSSION

7.1 | Point of view

The present study was performed to usability testing of two surgical and FFP2–N95 face masks, which are extensively used in Iran. The test usability output provided links to identify gaps and design needs and also led to a purposeful review of mask design recommendations. As a result, it implemented design recommendations as a concept design. The primary purpose of this study was to follow planning to design the face mask with anthropometric support and face form of different users and generalizable concept design so we could be exported more design information for a suitable respiratory protective cover against Covid-19.

One of the reasons for users to employ the surgical mask more than the FFP2 mask was its cheapness and availability in the Iranian market. For this reason, we could not consider the number of users to be equal. But the problem is that in the usability test, the average data is considered as the result. Although with the help of the usability test, it is possible to get an overview of the available products in a small range, given that the public lacks expertise in the field of product design and only examines it from a practical point of view, this study cannot be considered for all design parameters, and naturally, other methods must be used to achieve them. The most important difference between this study and others is the more comprehensive study of mask design parameters as usability variables. The results of the current study are consistent with those of Tang et al. (2009) and confirmed the leakage of N95 and surgical face masks in that the quality and usability affect the mask leading to the unwillingness of some users to use the mask to prevent disease (Tang et al., 2009). Unfortunately, these masks are not common and cannot be noticed in extensive use in different communities. If we assume that the price of a surgical mask is half the price of a more optimized design mask, we must also consider the length of time the mask can be used. Poor people may afford to buy three washable quality masks over 20 disposable low-quality masks. The location and type of conditions for using the mask will also determine the factors. The results of Liang et al. (2020) study showed that more evidence is still needed for the effectiveness of masks in a variety of situations, including the method of use, the permissible limit of use, and the effects of use (Liang et al., 2020). The difference between the present study and innovation from other research studies was the visual suggestion of the solution to overcome the problem instead of emphasizing the problem factors. This approach may speed up the process of solving problems. However, we also emphasized some problematic factors. On the contrary, it is very difficult to meet all the design needs in a study. Therefore, more research is needed to complete the design work. However, our emphasis, according to past research and the results of this study, is to focus on the new design of the mask, taking into account the ease of production, along with increasing the health efficiency and cost-effectiveness of the final product.

7.2 | Gaps and features

During the COVID-19 pandemic, the face mask is a means of prevention. However, the use of improper masks maybe leads to false self-confidence in some users because of the expense and scarcity of standard masks, poor supply chain management, and inefficiency of some governments in supplying the standard masks, so that using nonstandard masks provides a kind of temporary solution to commuting in public places and may not makes any prevention or maybe have weak and limited performance in this regard, and contrary to popular belief they may be used as a basis for increasing pathogens and transmitting the disease. Since public health aims to increase user access followed by making goods and services cheaper, instinctively, this will affect the quality of the proposed mask, and to reduce the last price of the product, the structure of the design must be considered simple. Meanwhile, due to the unknown nature of coronavirus and high expansion power, and the possibility of engaging users with different age groups and different anthropometric characteristics, to control it, more advanced technology in the field of design, materials, and manufacturing should be used. Naturally, this will lead to an increase in the final price. So, here, we come to the design paradox, which seems to need to be addressed, considering a set of rules. We checked a limited space. There are still a lot of opportunities for designing an optimal face mask. Based on the results of the theoretical phase of this study, we have proposed a concept for a mask design, which can be standardized and produced worldwide. The idea was to implement the results of previous studies and research on the product. We also included some new design criteria that were not discussed in previous research studies. Naturally, given the number of multiple parameters in a design and prioritizing them to satisfy the need, it cannot be claimed that the design of a product is flawless. Naturally, in

products with more components, this situation becomes more complicated. However, there are limitations to a design project, and further research may be needed to develop the product. In Table 6, we have listed the position of the mask design criteria according to the proposed design.

7.3 | Limitations and future works

During the COVID-19 pandemic, face-to-face access to users is limited. So, here, collected the usability data by convenience sampling and internet system. This made it impossible observational studied the shape and anthropometry of the user's face and to differentiate the usability results. It may be useful and necessary to restudy this issue and the impact of user gender and age on mask design in future research.

In cases where the health and safety of the user are desired, it is necessary to conduct a specific anthropometric study of the user community. Also, when patients inflicted with corona have been directly evaluated, there appears a change naturally in the presented results, and the lack of determining target users due to the inaccessibility to them was the most important limitation of the present study. The role of design here is to apply engineering interventions to prevent disease. The usability test in the most commonly used mask type, especially in developing countries, showed us that it is significantly different from the ideal design. The costs limit the quality of the product and the circulation of the medical product for the manufacturer, thus complicating the conceptual space of the design. Therefore, the main focus should be on the design in such a way that in addition to the speed of production and production, the quality of the product is also high and the price for the user is economical. The use of a modular design approach in this study led to the introduction of a new solution for a mask design, although in this study we have not yet been able to actually test the proposed mask on a great number of users. But this design could pave the way for future research and development after this type of mask is manufactured.

In the design presented, some parameters have been compensated, others need to be further investigated due to the presence of other components, and only the criteria related to the mask material for people with allergies have not been professionally studied in this study needing more scientific investigation because, in this study, users were chosen by convenience sampling. In case of investigating the mask material on allergy, allergic users should be examined.

Due to the epidemic crisis and vaccination problems, one of the most important issues is how users interact with each other. Some users are special. Like people with laryngeal, oral, or lung cancer. Users with skin allergies or deaf people. For example, deaf users have problems with current masks because they communicate with their lips. These cases also need expert review. We urge other researchers to develop Table 6 items, which have not yet reached a satisfactory level.

8 | CONCLUSION

Designing for usability and safety has always been complex. In the combined results of this study, which led to a proposed design, a modular design approach was used. Using this approach provided a condition for supporting more users, and with its help, we were able to provide the performance of adaptability with adjustability feature in the design. Also, to develop the final design of the UVW mask, it is necessary to re-evaluate the criteria in usability tests in this study on other face masks that are widely used. Results from the usability test of this study showed that the application of protocols to use FFP2–N95 and surgical masks cannot protect the individual against the viruses alone. Studies on using disposable masks and their role in environmental pollution along with the results from the usability tests indicate that drawbacks of design cannot be overcome only by focusing on behavioral issues. Therefore, in the conceptual design of mask UVW, it was suggested to focus on usability.

CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

ETHICS STATEMENT

This investigation is done based on the Helsinki statement and ethical aspects of human research.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available within the article. Raw data available on request from the authors.

ORCID

Bahram Ipaki https://orcid.org/0000-0002-1687-3602

REFERENCES

Applegate, W. B., & Ouslander, J. G. (2020). COVID-19 presents high risk to older persons. *Journal of the American Geriatrics Society*, *68*, 681. https://doi.org/10.1111/jgs.16426

Bernard Stoecklin, S., Rolland, P., Silue, Y., Mailles, A., Campese, C., Simondon, A., Mechain, M., Meurice, L., Nguyen, M., Bassi, C., Yamani, E., Behillil, S., Ismael, S., Nguyen, D., Malvy, D., Lescure, F. X., Georges, S., Lazarus, C., Tabaï, A., … Investigation Team. (2020). First cases of coronavirus disease 2019 (COVID-19) in France: Surveillance, investigations and control measures, January 2020. *Eurosurveillance*, *25*(6):2000094. https://doi.org/10.2807/1560-7917.ES.2020.25.6.2000094

Bowen, L. E. (2010). Does that face mask really protect you? *Applied Biosafety*, *15*(2), 67–71. https://doi.org/10.1177/153567601001500204

Branaghan, R. J., Hildebrand, E. A., & Foster, L. B. (2020). Designing for medical device safety, *Design for health* (pp. 3–29). Elsevier. https://doi.org/10.1016/B978-0-12-816427-3.00001-4

Cascella, M., Rajnik, M., Cuomo, A., Dulebohn, S. C., & Di Napoli, R. (2020). Features, evaluation and treatment coronavirus (COVID-19), StatPearls. StatPearls Publishing LLC.

Centor, R. M., & Fisman, D. N. (2020). Annals on call—Understanding the spread of COVID-19. *Annals of Internal Medicine*, *172*(6), OC1. https://doi.org/10.7326/a20-0001

Cho, T. L., Li, K.-C., Huang, C.-C., Chuang, L.-L., Chiang, C.-Y., Tsai, C.-C., Liu, Y. J., Huang, C. Y., & Hwang, K. P. (2015). Qualitative fit test of

N95 facial masks for medical staff. *Journal of Microbiology, Immunology and Infection*, *48*(2, suppl 1), S76. https://doi.org/10.1016/j.jmii.2015.02.270

Chua, M. H., Cheng, W., Goh, S. S., Kong, J., Li, B., Lim, J., Mao, L., Wang, S., Xue, K., Yang, L., Ye, E., Zhang, K., Cheong, W., Tan, B. H., Li, Z., Tan, B. H., & Loh, X. J. (2020). Face masks in the new COVID-19 normal: Materials, testing, and perspectives. *Research*, *2020*, 7286735. https://doi.org/10.34133/2020/7286735

Chughtai, A. A., Seale, H., Islam, M. S., Owais, M., & Macintyre, C. R. (2020). Policies on the use of respiratory protection for hospital health workers to protect from coronavirus disease (COVID-19). *International Journal of Nursing Studies*, *105*, 103567. https://doi.org/10.1016/j.ijnurstu.2020.103567

Dai, W., Zhang, H., Yu, J., Xu, H., Chen, H., Luo, S., & Lin, F. (2020). CT imaging and differential diagnosis of COVID-19. *Canadian Association of Radiologists Journal*, *71*, 195–200. https://doi.org/10.1177/0846537120913033

Fadare, O. O., & Okoffo, E. D. (2020). Covid-19 face masks: A potential source of microplastic fibers in the environment. *Science of the Total Environment*, *737*, 140279. https://doi.org/10.1016/j.scitotenv.2020.140279

Foster, W. (1997). *Drawing: Faces: Learn to draw step by step*. Walter Foster Publishing.

Geisen, E., & Romano Bergstrom, J. (2017). Developing the usability testing protocol. In E. Geisen & J. Romano Bergstrom (Eds.), *Usability testing for survey research* (pp. 111–129). Morgan Kaufmann.

Ho, K.-F., Lin, L.-Y., Weng, S.-P., & Chuang, K.-J. (2020). Medical mask versus cotton mask for preventing respiratory droplet transmission in micro environments. *Science of the Total Environment*, *735*, 139510. https://doi.org/10.1016/j.scitotenv.2020.139510

Institute of Medicine, Board on Health Sciences Policy, Committee for the Assessment of the NIOSH Head-and-Face Anthropometric Survey of U.S. Respirator Users, Bailar, J. C., III, Meyer, E. A., & Pool, R. (2007). *Assessment of the NIOSH head-and-face anthropometric survey of U.S. respirator users*. National Academies Press.

Ipaki, B., Amirkhizi, P. J., & Heidari, A. (2021). Optimal design method for orthopaedic footwear insole customization based on anthropometric data and NURBS system. *Journal of Design Research. Advance online publication*.

Kirillov, V., Bunchev, A., & Chirkin, A. (2013). On means of individual protection of respiratory organs of the workers (literature review). *Meditsyna Truda i Promyshlennaya Ekologiya*, *4*, 25–31.

Klompas, M. (2020). Coronavirus disease 2019 (COVID-19): Protecting hospitals from the invisible. *Annals of Internal Medicine*, *172*, 619–620. https://doi.org/10.7326/m20-0751

Lee, S., & Ha, T. (2019). Changes in perceived usability and aesthetics with repetitive use in the first use session. *Human Factors and Ergonomics in Manufacturing & Service Industries*, *29*(6), 517–528. https://doi.org/10.1002/hfm.20814

Leung, C. C., Lam, T. H., & Cheng, K. K. (2020). Mass masking in the COVID-19 epidemic: People need guidance. *The Lancet*, *2*, 156. https://doi.org/10.1016/S0140-6736(20)30520-1

Liang, M., Gao, L., Cheng, C., Zhou, Q., Uy, J. P., Heiner, K., & Sun, C. (2020). Efficacy of face mask in preventing respiratory virus transmission: A systematic review and meta-analysis. *Travel Medicine and Infectious Disease*, *36*, 101751. https://doi.org/10.1016/j.tmaid.2020.101751

Meyer, M. H., & Lehnerd, A. P. (1997). *The power of product platforms*. Free Press.

Ng, K., Poon, B. H., Kiat Puar, T. H., Shan Quah, J. L., Loh, W. J., Wong, Y. J., Tan, T. Y., & Raghuram, J. (2020). COVID-19 and the risk to health care workers: A case report. *Annals of Internal Medicine*, *172*, 766–767. https://doi.org/10.7326/l20-0175

Null, R. (2013). *Universal design: Principles and models*. Taylor & Francis.

O'Kelly, E., Arora, A., Pirog, S., Ward, J., & Clarkson, P. J. (2021). Comparing the fit of N95, KN95, surgical, and cloth face masks and assessing the accuracy of fit checking. *PLOS One*, *16*(1), e0245688. https://doi.org/10.1371/journal.pone.0245688

Patel, A., Jernigan, D. B., & 2019-nCoV CDC Response Team. (2020). Initial public health response and interim clinical guidance for the 2019 novel coronavirus outbreak–United States, December 31, 2019-February 4, 2020. *Morbidity and Mortality Weekly Report*, *69*(5), 140–146. https://doi.org/10.15585/mmwr.mm6905e1

Pheasant, S. (1996). *Bodyspace: Anthropometry, ergonomics and the design of work*. Taylor & Francis.

Pyankov, O. V., Bodnev, S. A., Pyankova, O. G., & Agranovski, I. E. (2018). Survival of aerosolized coronavirus in the ambient air. *Journal of Aerosol Science*, *115*, 158–163. https://doi.org/10.1016/j.jaerosci.2017.09.009

Radonovich, L. J., Jr., Simberkoff, M. S., Bessesen, M. T., Brown, A. C., Cummings, D., Gaydos, C. A., Los, J. G., Krosche, A. E., Gibert, C. L., Gorse, G. J., Nyquist, A. C., Reich, N. G., Rodriguez-Barradas, M. C., Price, C. S., Perl, T. M., & ResPECT investigators. (2019). N95 respirators vs medical masks for preventing influenza among health care personnel: A randomized clinical trial. *Journal of the American Medical Association*, *322*(9), 824–833. https://doi.org/10.1001/jama.2019.11645

Reis, C. I., Freire, C. S., Fernández, J., & Monguet, J. M. (2011). Patient centered design: Challenges and lessons learned from working with health professionals and schizophrenic patients in e-therapy contexts. Paper presented at the ENTERprise Information Systems, Berlin, Heidelberg.

Ren, S.-Y., Gao, R.-D., & Chen, Y.-L. (2020). Fear can be more harmful than the severe acute respiratory syndrome coronavirus 2 in controlling the corona virus disease 2019 epidemic. *World Journal of Clinical Cases*, *8*(4), 652–657.

Rosson, M. B., & Carroll, J. M. (2002). Usability evaluation. In M. B. Rosson & J. M. Carroll (Eds.), *Usability engineering* (pp. 227–271). Morgan Kaufmann.

Sangkham, S. (2020). Face mask and medical waste disposal during the novel COVID-19 pandemic in Asia. *Case Studies in Chemical and Environmental Engineering*, *2*, 100052. https://doi.org/10.1016/j.cscee.2020.100052

Shruti, V. C., Pérez-Guevara, F., Elizalde-Martínez, I., & Kutralam-Muniasamy, G. (2020). Reusable masks for COVID-19: A missing piece of the microplastic problem during the global health crisis. *Marine Pollution Bulletin*, *161*, 111777. https://doi.org/10.1016/j.marpolbul.2020.111777

Suen, L. K. P., Guo, Y. P., Ho, S. S. K., Au-Yeung, C. H., & Lam, S. C. (2020). Comparing mask fit and usability of traditional and nanofibre N95 filtering facepiece respirators before and after nursing procedures. *Journal of Hospital Infection*, *104*(3), 336–343. https://doi.org/10.1016/j.jhin.2019.09.014

Tang, J. W., Liebner, T. J., Craven, B. A., & Settles, G. S. (2009). A schlieren optical study of the human cough with and without wearing masks for aerosol infection control. *Journal of the Royal Society Interface*, *6*(suppl 6), S727–S736. https://doi.org/10.1098/rsif.2009.0295.focus

Vlasak, R., Luytjes, W., Spaan, W., & Palese, P. (1988). Human and bovine coronaviruses recognize sialic acid-containing receptors similar to those of influenza C viruses. *Proceedings of the National Academy of Sciences of the United States of America*, *85*(12), 4526–4529. https://doi.org/10.1073/pnas.85.12.4526

World Health Organization. (2020). Coronavirus disease (COVID-19). https://www.who.int/emergencies/diseases/novel-coronavirus-2019/coronavirus-disease-answers?query=face%2Bmask%26amp;referrerPageUrl=https%3A%2F%2Fwww.who.int%2Femergencies%2Fdiseases%2Fnovel-coronavirus-2019%2Fcoronavirus-disease-answers

Xiao, L., Sakagami, H., & Miwa, N. (2020). A new method for testing filtration efficiency of mask materials under sneeze-like pressure. *In Vivo*, *34*(3 suppl), 1637–1644. https://doi.org/10.21873/invivo.11955

Zhang, X., Li, H., Shen, S., Rao, Y., & Chen, F. (2016). An improved FFR design with a ventilation fan: CFD simulation and validation. *PLOS One*, *11*(7), e0159848. https://doi.org/10.1371/journal.pone.0159848

Zhou, S. S., Lukula, S., Chiossone, C., Nims, R. W., Suchmann, D. B., & Ijaz, M. K. (2018). Assessment of a respiratory face mask for capturing air pollutants and pathogens including human influenza and rhinoviruses. *Journal of Thoracic Disease*, *10*(3), 2059–2069. https://doi.org/10.21037/jtd.2018.03.103

How to cite this article: Ipaki, B., Merrikhpour, Z., Taheri Rizi, M. S., & Torkashvand, S. (2021). A study on usability and design parameters in face mask: Concept design of UVW face mask for COVID-19 protection. *Hum. Factors Man.* 31, 664–678. https://doi.org/10.1002/hfm.20934