

## RESEARCH ARTICLE

# Assessing personal protective equipment needs for healthcare workers

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**Abstract**

**Background:** Personal protective equipment (PPE) is critical for healthcare workers (HCWs) since it acts as a barrier to infection transmission; however, current PPE is not ideally suited to their needs due to limitations in protection and comfort. Thus, the purpose of this study was to identify major issues of current PPE for body protection and assess its needs within health care.

**Methods:** An online survey was conducted with a convenience sample of 200 U.S. healthcare professionals who interact with patients. The survey was designed to identify the types of PPE that HCWs currently use, assess current PPE design features for body protection, examine the effect of PPE design features for body protection, and HCWs' years of work experiences on overall PPE acceptability, and explore current PPE maintenance practices. Both quantitative and qualitative data were used for analyses.

**Results:** This study showed the need for current PPE improvement in terms of fit, comfort, mobility, and donning and doffing for HCWs' safety and health. Donning and doffing plays an important role in HCWs' overall acceptance of PPE for body protection. This study revealed that most HCWs dispose of their PPE in a trashcan in a healthcare unit and non-disposed PPE is laundered at home, which may expose their family members to a health risk if a proper precaution is not followed.

**Conclusion:** This study provides critical insights for the needs of (a) novel PPE design research and (b) proper donning and doffing training and its strict regulatory effort to ensure HCWs' safety and health.

**KEYWORDS**

donning and doffing, healthcare workers, personal protective equipment, safety and health, wearer acceptability

## 1 | INTRODUCTION

The world is presently experiencing a widespread outbreak of the COVID-19 pandemic that is highly contagious from person to person

transmission.<sup>1</sup> Besides this pandemic, there are other documented overexposures to microorganisms that are commonly carried through blood, body fluids, and other potentially infectious materials, including Ebola hemorrhagic fever, hepatitis B, hepatitis C, and human immunodeficiency virus.<sup>2-6</sup> In such a crisis, healthcare workers (HCWs) face multiple challenges regarding patient care, such as handling infectious

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samples for diagnostics and potential health risks from direct contact with infectious patients.<sup>7</sup> To provide safety and protection, personal protective equipment (PPE), including clothing, respirators, gloves, and covering materials, is used to prevent the transfer of microorganisms and body fluids.<sup>8,9</sup> PPE is strategically used widely in healthcare facilities to minimize the passage of microbes to patients and HCWs.<sup>10</sup>

PPE is critical for healthcare workers (HCWs) since it acts as a barrier to infection transmission.<sup>11</sup> However, PPE itself and its standards have not changed over recent years to address needs within the healthcare environment. The current COVID-19 outbreak has raised much awareness of PPE for the frontline HCWs from infectious diseases. According to the American Nurses Association's recent survey with more than 20 000 HCWs, during the COVID-19 outbreak, 76% of HCWs reported extreme concerns of current PPE, and 85% worried about keeping their families safe from becoming infected.<sup>12</sup> Thus, extensive evidence-based PPE design research for HCWs is critical for their safety and overall public health.

Extensive studies have demonstrated how the proper use of PPE and the material used for PPE play a significant role in decreasing the transmission of bacteria and viruses, thus reassuring the PPE use as a critical component of isolation precaution.<sup>13-17</sup> However, current PPE is not ideally suited to the needs of HCWs due to limitations in protection and comfort, such as insufficient capture of airborne pathogens, difficulties in communication through materials, potential fluid penetration, poorly executed fit and sizing, and complicated procedures for donning and doffing.<sup>14,18,19</sup>

Although Centers for Disease Control and Prevention (CDC)<sup>20,21</sup> provides step-by-step guidance about how to don and doff PPE to protect HCWs from the severe infectious environment, the urgency of the work environment makes it a challenge to adhere to this regulatory guideline and thus makes them extremely susceptible to risk of infection. Proper donning and doffing is also challenged because of lack of human factors' considerations within the current PPE design as well as inappropriate layout and location of donning and doffing stations,<sup>19,22</sup> which leads a research inquiry to develop an innovative PPE that allows for protection efficiency and greater efficiency in the donning and doffing procedure. These PPE development strategies have examined other populations such as firefighters, agricultural workers, and construction workers<sup>23-27</sup>; however, there is a paucity of data regarding PPE design and development for HCWs. The need for further assessment of PPE for HCWs is of utmost importance because they are the ones spending the most significant time in the infectious environment with the most contagious people.

Thus, the purpose of this study was to identify major issues of current PPE for body protection and assess HCWs' PPE needs within a healthcare setting. The specific objectives were as follows: (a) identify the types of PPE that HCWs currently use for overall protection; (b) assess the current PPE design features for body protection, including fit, mobility, comfort, donning and doffing, and aesthetic; (c) examine the effect of PPE design features for body protection and HCWs' years of work experiences on overall PPE acceptability; and (d) explore the current PPE maintenance practices among HCWs.

## 1.1 | PPE for healthcare workers

The multiple issues that influence the success of PPE could include the following: (a) clothing that protects the worker from the hazard at the expense of mobility or thermal comfort that affects work performance; (b) clothing that does not fit well has been proven to limit protection and safety; (c) clothing components not considered from a systems perspective may leave areas of the body exposed to the environmental hazard; and (d) socio-cultural barriers may affect not wearing proper PPE (eg, the availability of appropriate and cost-effective PPE, insufficient training and evidence of support among workers in these sectors).<sup>28</sup> Resolving these complex issues requires materials and prototype development, testing, design, and redesign in a continuous process using systems thinking and multidisciplinary research collaboration to find optimum solutions.

PPE in a healthcare setting is mainly used to protect the nose and mouth, body, hands, eyes and face, head, and feet. Protective clothing, including gowns, coveralls, aprons, and scrubs, is a body protection barrier to prevent the penetration of body fluids and liquids to the wearer's skin and clothing,<sup>20,29</sup> which is the focus of this study. PPE requirements for HCWs vary as per the nature of the virus and disease type. Rules for protecting workers from Ebola, which were issued by CDC, stated that hospital workers treating Ebola patients should wear double sets of gloves, disposable hoods with full-face shields, and special masks.<sup>5</sup> During the COVID-19 outbreak, CDC issued new rules that HCWs should use isolation gown, N95 filtering respirator, or facemask if a respirator is not available, face shield, or goggle, and glove when carrying for patients with confirmed or suspected COVID-19.<sup>8</sup> The new CDC guidelines focus on PPE, giving hospitals and clinics more specific instructions about gloves, gowns, and facemasks, and how they should be put on and taken off.<sup>5,10</sup>

In PPE design, there are several issues remaining in isolation gown design, which include the following: (a) donning and doffing time and procedure; (b) the gown barrier effectiveness, which includes the seams and closures; and (c) clothing thermal comfort, movement comfort, sizing and fit.<sup>14</sup> Proper training on how to put on and take off PPE may mitigate the risk of infection<sup>30</sup>; however, the study demonstrates that even with the proper training, up to 17% of HCWs are still at high risk of getting infected while treating the Ebola virus diseases.<sup>31</sup> Notably, the doffing period of PPE is considered a high-risk time of self-contamination and pathogen transmission because of involving multiple steps and needing another person's assistance.<sup>32,33</sup> The recent study showed that 90% of HCWs' doffing practices did not follow the CDC guideline in terms of doffing sequence, doffing technique, or proper use of PPE,<sup>34</sup> which leads to HCWs' self-contamination by transferring germs to the skin or clothing.<sup>35</sup> Another study reported the delay of emergency care because of the complicated donning procedure of PPE.<sup>36</sup> These findings reassure the importance of donning and doffing procedures of PPE for HCWs' safety and protection.

Moreover, the effectiveness of PPE relies on other factors including material characteristics, sizing and fit, comfort, mobility, the layout of the environment, and interfaces among all of these.<sup>14,22,37</sup> The

medical personnel experiences discomfort and heat stress while wearing PPE, which eventually impacts their job performance.<sup>38</sup> The performance of comfort and mobility is related to the sizing and fit of PPE. According to the Occupational Safety and Health Administration and European Center for Disease Prevention and Control, a “one size fits all” approach fails to provide adequate PPE fitting to HCWs.<sup>18,39</sup> Also, modification of the design of the environment (eg, PPE doffing area) is important to enhance HCWs' safety.<sup>22</sup> It is crucial to improve the efficacy and effectiveness of PPE with attention to improving the functionality and addressing wearability, compliance, and communication for HCWs' safety and health.

## 1.2 | PPE use, maintenance, and care

Several studies demonstrate that improper cleaning or maintenance of PPE leads dissemination of microorganisms through textiles or PPE.<sup>15,17,40</sup> CNN<sup>41</sup> raised concerns about inappropriate uses of PPE by HCWs and the general public during the COVID-19 pandemic and addressed the needs of appropriate PPE maintenance and care. HCWs generally laundered their PPE at workstations, professional laundering services, or home,<sup>42</sup> despite the possibility of spreading microorganisms from any laundering services if proper procedures are not followed.<sup>43</sup> Especially, laundering at home posed the greatest risk for both HCWs and their family members getting infected by microbial diseases.<sup>44</sup> Additional studies<sup>45-47</sup> support this finding as well. Although CDC provides the laundering guideline for infection control in healthcare facilities,<sup>48</sup> limited research is available on HCWs' PPE laundering practices and their awareness of the proper PPE maintenance and care, which is urged for further research exploration for HCWs' long-term safety and health.

## 2 | MATERIALS AND METHODS

A quantitative research methodology using an online survey technique was employed for this exploratory study. University's Institutional Review Board approval was obtained before any data collection.

### 2.1 | Study sample and data collection procedure

Using a nationwide convenience sampling method, HCWs, aged 18 years old and over who live in the United States and interact with patients, were recruited through two sources, nursing school in one southeast university and Qualtrics data panel. A previous study confirmed the internal and external validity of the data from Qualtrics sampling panel.<sup>49</sup> Using the Qualtrics platform, the survey questionnaire was first pre-tested by a few disciplinary experts in nursing and apparel to ensure the clarity and consistency of the content.

The online survey started with an informed consent letter, describing the study purpose,

the survey procedure and incentive, eligibility to be a study participant, and a participant's right when participating in the survey. Participants were first guided to the context of this study, stating as “The personal protective equipment (PPE) consists of garments or equipment placed to protect the healthcare workers or any other persons from infection. The following questions ask you about your experiences of using PPE in a healthcare setting.” They were then asked to respond to the survey questions, which took 10 to 15 minutes to complete. All participants were compensated for their time.

### 2.2 | Measures

The online survey questionnaire was composed of four parts: (a) demographics; (b) HCWs' current experience of different types of PPE use; (c) HCWs' opinions about PPE for body protection, PPE design features, and overall PPE acceptability; and (d) their PPE maintenance practices. Demographic questions consisted of participants' age, gender, ethnicity, geographical region, community type, years of working experiences, and role in a healthcare setting.

Participants were asked six questions about the types of PPE they have used or are currently using to protect eyes, nose and mouth, hands, body, head, and feet at their workstation. Three questions were associated with PPE maintenance practices among HCWs: (a) How do you treat PPE after wearing?; (b) Where do you dispose your PPE?; and (c) How do you launder your PPE? One open-ended question was included in the survey to explore the challenges HCWs face while wearing PPE for body protection from the infectious environment.

Regarding HCWs' thoughts about current PPE design, we did limit to ask their opinions of PPE for body protection, including scrubs (tops/pants), gowns, coveralls, disposable aprons, and reusable aprons, in a healthcare setting. The closed-ended questions consisted of 34 items related to (a) PPE design features including 13 items of fit, 10 items of mobility, 6 items of comfort, 2 items of donning and doffing, and 2 items of aesthetic, and (b) 1 item related to overall PPE acceptability. All measures were adapted and modified from previous studies<sup>25,26</sup> and measured on a five-point Likert-type scale, ranging from “strongly disagree” (1) to “strongly agree” (5).

### 2.3 | Data analysis

Quantitative data were analyzed with SPSS 26 for frequency, descriptive analysis, and reliability check. Descriptive statistics and frequencies were used to analyze the participants' demographic information, types of PPE that HCWs use, PPE maintenance practices, and assessment of PPE design features. Data from the open-ended question were analyzed using a content analysis approach to identify recurring concepts. The Cronbach's  $\alpha$  was used to measure the internal consistency of the survey questionnaire, resulting in .90 for this study,

which is greater than the acceptable value of .70.<sup>50</sup> Thus, the reliability of the survey questionnaire contents in this study was confirmed.

SAS 9.4 was used to run the baseline category logit model within logistic regression<sup>51</sup> to examine the effect of PPE design features (fit, mobility, comfort, donning and doffing, and aesthetic) and years of work experiences on overall PPE acceptability. In this model, predictors were fit, mobility, comfort, donning and doffing, aesthetic, and years of work experiences, and overall PPE acceptability was assigned as a response variable. The likelihood ratio test was performed to determine the model's significance. The backward selection process determined the significance of predictors. Later, a chi-square ( $\chi^2$ ) goodness of fit test was performed to confirm the model's validity.

### 3 | RESULTS AND DISCUSSION

#### 3.1 | Sample characteristics

A total of 200 valid responses were used for the data analysis. Participants' ages ranged from 19 to 73 years old, with a mean age of 38. Ninety percent of the participants were females, and 10% were males. The majority was White/European American (83.5%), followed by African American (9.0%), Hispanic American/Latino (5.0%), and others (2.5%). Approximately 34% of the participants were performing their healthcare practices within the geographical region of the South, followed by Midwest (30.0%), Northeast (20.5%), and West (15.5%). Among those, 43.5% lived in a suburban community, followed by urban (30.0%) and rural (26.5%). Of the participants, 36% were classified as professional nurses, including registered nurses, certified nursing assistants, and licensed practical nurses. The rest consisted of student nurses (13.0%), medical assistants (11%), caregivers (9.5%), medical technologists (8.0%), administrators (8.0%), therapists (6.0%), and others (8.5%), including physicians, pharmacists, and nutritionists. Their work experiences in a healthcare setting ranged from 1 to 50 years, with a mean experience of 13 years.

#### 3.2 | Assessment of current PPE types

The first study objective was to identify the types of PPE that HCWs currently use for overall protection. As shown in Table 1, among 200 participants, 64% had experiences of using face shields, followed by 54.5% of goggles for eye protection. For nose and mouth protection, 91% and 46.5% were using masks and respirators, respectively. For hand protection, 91.5% and 39% were using examination gloves and rubber gloves, respectively. For body protection, 83% were using gowns, followed by 80.5% of scrubs including tops and pants, 31% of disposable aprons, 18.5% of coveralls, and 13.5% of reusable aprons. For head protection, 37% and 22% were using head covers and hoods, respectively. For foot protection, 82.5% did use shoe covers and only 9% used rubber boots.

The results indicate that HCWs widely use face shield, mask, examination gloves, gown, head cover, and shoe covers to protect

**TABLE 1** Different types of PPE used by HCWs for protection

PPE category	Frequency (n)	Percentage (%)
Eye protection		
Goggles	109	54.5
Face shield	128	64.0
Nose and mouth protection		
Mask	182	91.0
Respirator	93	46.5
Hand protection		
Examination gloves	183	91.5
Heavy duty rubber gloves	78	39.0
Body protection		
Scrubs (tops/pants)	161	80.5
Gown	166	83.0
Coverall	37	18.5
Reusable apron	27	13.5
Disposable apron	62	31.0
Head protection		
Hood	44	22.0
Head cover	74	37.0
Foot protection		
Shoe covers	165	82.5
Rubber boots	18	9.0

Note: Frequency (n) does not equal the total number of study participants (N = 200). In the survey, the participants were asked to select all types of PPE they have used or are currently using.

their eyes, nose and mouth, hands, body, head, and feet from various known and unknown environmental crises. This finding is evidenced by what frontline HCWs are currently suggested to wear for safety and protection from the COVID-19 pandemic. Under this crisis, we often see that frontline workers wear masks, gloves, isolation gowns, N95 respirators, goggles, and face shields when handling virus-infected individuals.<sup>52-54</sup>

#### 3.3 | Assessment of current PPE design features for body protection

The second study objective was to assess the current PPE design features for body protection, including fit, mobility, comfort, donning and doffing, and aesthetic. The results revealed that the mean values of PPE were higher than 3 (on the 1-5 scale) for the following features: fit (M = 3.45, SD = 0.56), comfort (M = 3.38, SD = 0.72), mobility (M = 3.44, SD = 0.69), and donning and doffing (M = 3.71, SD = 0.87) (see Table 2). These quantitative results demonstrate that HCWs think that current PPE (scrubs, gowns, coveralls, and apron) for body protection meet their needs of fit, comfort, mobility, and donning and doffing. The mean value of PPE in terms of the aesthetic feature was lower than 3 (M = 2.53, SD = 0.87), revealing that HCWs are not pleased with their current PPE

**TABLE 2** The mean value of PPE design features for body protection (N = 200)

PPE design features for body protection	Mean	SD
<i>Donning and doffing</i>	3.71	0.87
I can easily put on my PPE.	3.88	0.85
My PPE is easy to put on and take off.	3.55	0.97
<i>Mobility</i>	3.44	0.69
I have freedom to move my arms while wearing PPE.	3.80	0.87
It is easy to move in wearing PPE.	3.57	0.98
I have trouble moving quickly wearing my PPE.	3.29	1.03
My movement is restricted when wearing my PPE.	3.17	1.04
It is easy to move in wearing my PPE.	3.34	0.97
I am able to move my arms and legs freely when wearing my PPE.	3.59	0.88
I have trouble lifting my arms and legs up high when wearing my PPE.	3.37	1.05
It is easy to lift my arms and legs wearing my PPE.	3.42	0.94
My body movement is challenged by wearing my PPE.	3.21	1.05
My PPE is too tight and makes it difficult to bend my body.	3.68	0.94
<i>Fit</i>	3.41	0.58
I am satisfied with the fit of my PPE.	3.99	0.84
My PPE is tight.	3.31	1.00
Overall, my PPE fits well.	3.59	0.93
My PPE is too big for my body.	3.36	0.99
The length of my PPE is too long.	3.08	1.18
The size range of my PPE offered is appropriate.	3.24	1.14
The waist on my PPE is too tight.	3.33	1.05
The waist is too big on my PPE.	3.72	0.95
My PPE have an acceptable crotch length.	3.36	1.12
The crotch on my PPE is too loose.	3.36	0.92
The crotch is too low on my PPE.	3.28	0.99
The crotch is too tight on my PPE.	3.31	1.00
The crotch is ripped out on my PPE.	3.62	0.90
<i>Comfort</i>	3.38	0.72
I feel comfortable wearing my PPE.	3.89	1.01
I feel fatigued wearing my PPE.	3.53	1.17
My PPE is heavy.	3.71	1.09
My PPE material is stiff.	3.18	1.15
My PPE provides me rough feeling next to my body.	3.21	1.12
My PPE material is non-breathable.	2.80	1.08
<i>Aesthetic</i>	2.53	0.87
My PPE is attractive.	2.12	1.04
I like my PPE.	2.94	1.01

Note: Each item was measured using a 5-point Likert Scale, ranging from "strongly disagree" (1) to "strongly agree" (5).

aesthetic. Despite these mean differences, the mean values of all PPE design features scored in a neutral range from 2.53 to 3.71, which indicates that there is room for further improvement in PPE design features for HCWs. The results from the qualitative data further assisted our understanding of the current PPE challenges.

In response to the open-ended question, "Do you have any other challenge of PPE (eg, scrubs (tops/pants), gown, coverall, disposable apron, reusable apron) for body protection in your healthcare setting?" 31% of the participants considered comfortability as the biggest challenge when wearing PPE, followed by sizing and fit (27.34%), donning and doffing (14.39%), movement (12.33%), material durability (11.52%), and others (3.42%) such as easy to use and PPE weight. The qualitative data findings symbolize the challenges HCWs currently face in the area of PPE's comfortability, fit, donning, and doffing. These findings also are supported by the findings from previous studies on inappropriate sizing and fit of PPE in health care,<sup>18</sup> HCWs' experiences of discomfort while wearing PPE because of the material property,<sup>38</sup> and HCWs' job performance delay because of the complicated donning and doffing process of PPE.<sup>36</sup>

None of the participants addressed the aesthetic feature of PPE as their concern in the open-ended response. This may be interpreted as the aesthetic feature is not much important for HCWs compared with other utilitarian features (eg, donning and doffing) that directly influence their work performance. Further research is warranted in this area.

### 3.4 | Overall PPE acceptability for Body Protection

The third study objective was to examine the effect of PPE design features (eg, fit, mobility, comfort, donning and doffing, aesthetic) and HCWs' years of work experiences on overall PPE acceptability for body protection. As shown in Table 3, the likelihood ratio test

**TABLE 3** PPE acceptability model testing results (N = 200)

	df	Chi-Square ( $\chi^2$ ) Value
Full model (Significance test)		
Likelihood ratio test	36	83.41***
Full Model (by variable selection)		
Years of work experiences in a healthcare setting	16	0.98
Mobility	4	0.28
Comfort	4	0.12
Fit	4	0.12
Aesthetic	4	0.11
Donning and doffing	4	32.14***
Reduced Model (Significance test)		
Likelihood ratio test	4	44.06***
Model validity test (Full vs Reduced model)		
Goodness of fit test	32	39.34

Abbreviation: df, degrees of freedom.

\*\*\* $P < .001$ .

**TABLE 4** The Odds Ratio Estimation from PPE Acceptability Model (N = 200)

Predictor Variable	Agreement on the Response Variable: PPE Acceptability	Odds Ratio (OR)	95% Confidence Interval (CI)
Donning and Doffing	Disagree	0.20	[0.03, 1.11]
	Neutral	0.31	[0.06, 1.52]
	Agree	0.64	[0.14, 2.97]
	Strongly agree	2.37	[0.48, 11.61]

Note: "Strongly disagree" was set as a reference category.

confirmed the significance of the full model on overall PPE acceptability, which contained all of the five predictors (fit, mobility, comfort, donning and doffing, aesthetic, and work experience) ( $\chi^2_{[36]} = 83.41$ ;  $P < .001$ ). The backward selection process determined the significance of only donning and doffing predictor on overall PPE acceptability ( $\chi^2_{[4]} = 32.14$ ;  $P < .001$ ). Thus, except for donning and doffing, all other predictors were omitted within the reduced model on overall PPE acceptability. The likelihood ratio test confirmed the significance of the reduced model ( $\chi^2_{[4]} = 44.06$ ;  $P < .001$ ). The goodness of fit test confirmed the validity of the reduced model compared with the full model of overall PPE acceptability ( $\chi^2_{[32]} = 39.34$ ;  $P > .05$ ).

According to the odds ratio estimation from the overall PPE acceptability model shown in Table 4, HCWs are more likely "Strongly agree" than "Strongly disagree" to accept PPE based on the donning and doffing feature, OR = 2.37, 95% CI [0.48, 11.61], which means that the donning and doffing feature plays a vital role on HCWs' overall PPE acceptance. When considering HCWs' working environments under the COVID-19 crisis, this feature can be an actual matter of their safety and protection. Challenges in the PPE donning and doffing procedure may lead them to expose a risky environment because virus transmissions can occur through improper PPE donning and doffing process interacting with many other associated factors.<sup>19,22,35</sup>

The finding of this study supports the importance of proper PPE donning and doffing as well as overcoming the PPE design challenge, especially donning and doffing feature, for HCWs' safety and protection.<sup>30,31</sup> The findings of this study and previous studies warrant future research on novel PPE design and development, which reconfigures a safe and protective way of donning and doffing.

### 3.5 | Assessment of PPE maintenance practices

The fourth study objective was to explore the PPE maintenance practices among HCWs. Regarding the PPE use and maintenance, 87% of the participants disposed of their PPE after a single use; among them, 61% disposed it to a trashcan or garbage bag, and the rest put it into a biohazard bag. Thirty-one percent of the participants laundered their PPE after the use; among them, the majority of PPE laundering was done at their home (54.8%), taken care by their workstation (38.7%), and professional laundering services (6.5%). These findings demonstrate that PPE maintenance and after use care might not be adequately instructed at the job site; thus, further investigation is needed.

## 4 | CONCLUSION

This study revealed that face shield, mask, examination gloves, gown, head cover, and shoe covers are commonly used by HCWs to protect their eyes, nose and mouth, hands, body, head, and feet in health care. The findings also revealed the need for current PPE improvement for body protection in terms of fit, comfort, mobility, and donning and doffing. Especially, donning and doffing is the most important design feature of PPE as it is directly related to HCWs' overall PPE acceptability for body protection. A novel PPE design considering a holistic approach to the whole PPE ensemble is one way to ensure their safety and protection against infectious diseases.

In this study, none of the participants addressed the aesthetic feature as a concern when wearing PPE. For HCWs in their workstation, it may be interpreted as the aesthetic feature is not much needed compared with other utilitarian features (eg, donning and doffing, comfort, fit) that directly influence their work performance and safety. This study also reveals that most HCWs dispose of their PPE in a trash can in a healthcare unit, and non-disposed PPE is laundered at home, which may expose family members to a health risk if a proper precaution is not followed. In the COVID-19 crisis, when PPE usage has been drastically increased, it is equally important to proper post-maintenance and care of PPE. Further research is also recommended to examine the PPE maintenance practice and its influence on HCWs and their family members' safety and health.

The key features identified in this study would be a great starting point for developing novel PPE to meet HCWs' safety and health from the infectious environment. The development and dissemination of effective PPE require analysis and research in a wide variety of research areas, including anthropometrics and ergonomics, novel functional textile and materials science, advanced materials testing and evaluation, product design, and evaluation, as well as policy-making (eg, standards/regulations). Further research should incorporate the findings of this study into the above diverse research areas.

Although this study contributes to the existing literature and practitioners, it has a few limitations, which call for future research. In this study, the PPE features were extracted from the previous studies, which might not cover all important quality features required for PPE in different healthcare settings. Future research is recommended to identify other quality features that may play a crucial role in PPE using other research methods besides the survey. A qualitative approach can be taken by future researchers to provide a deeper understanding

of the different needs of PPE design features for HCWs. The study was limited to PPE for body protection to assess its design features and maintenance. Considering a holistic approach to the whole PPE ensemble and how the individual components interact is important, further research is recommended to investigate a thorough assessment of the different types of PPE and their interfaces in health care. Researchers and product developers need to consider PPE as a whole system consisting of different parts and develop PPE in a systematic way.

Most of the study participants were recruited through the Qualtrics data panel, which enabled us to quickly obtain the nationwide convenience sample of HCWs in the United States; however, the sampling pool was limited to those who were approachable by this service firm and had access to the online survey. The study sample in this study was skewed toward nurses; among 200 participants, half of the survey responses were from nurses, limiting the ability to generalize the study findings. Thus, it is recommended for future researchers to utilize a sample consisting of a wide range of HCWs and reassess their PPE needs. Despite having some limitations, this study provides critical insights for the needs of (a) novel PPE design research using a holistic approach and (b) proper donning and doffing training and its strict regulatory effort to ensure HCWs' safety and health.

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## CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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All authors have read and approved the final version of the manuscript.

Young-A Lee had full access to all of the data in this study and takes complete responsibility for the integrity of the data and the accuracy of the data analysis.

## TRANSPARENCY STATEMENT

This manuscript is an honest, accurate, and transparent account of the study being reported. No important aspects of the study have been omitted. Any discrepancies from the study as planned (and, if relevant, registered) have been explained.

## INSTITUTION AND ETHICS APPROVAL AND INFORMED CONSENT

Institutional review and ethics approval was obtained from the Human Subjects Office at Auburn University in Auburn, Alabama, USA. A waiver of written consent was granted since this study involved online survey where participants were recruited through an online platform.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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