Fit Analysis of Personal Protective Equipment Across Healthcare Worker Demographics During COVID-19

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

The disparity caused by medical technology is widespread, ranging from pulse oximeters that miss hypoxia three times more in black patients to medical training devices that are based on 6'2 men (GTSimulators, 2024; Johansson et al., 2021). The products that engineers develop play a role in shaping the world, and in a society plagued with systemic inequality, a passive approach to design will inevitably perpetuate existing disparities. All engineers hold inherent biases; without recognizing and acknowledging these, it is difficult to consider the diverse needs of all their potential users. Engineers have a responsibility to analyze the broader social impact of their work and hopefully limit the negative ramifications of their designs. To better understand how inequalities in medical technologies manifest, this paper will present a case study of personal protective equipment (PPE) fit disparities during the COVID-19 pandemic. Specifically, it will address the question: How did the social and organizational structures surrounding PPE production and distribution during the COVID-19 pandemic contribute to discrepancies in fit and functionality across various healthcare worker demographics?

Due to the COVID-19 pandemic's complex and hectic nature, it offers a perfect scenario to analyze the many different factors that contribute to the impact of a technology. With the massive increase in PPE manufacturing and use during the pandemic, issues regarding its sizing and fit became very apparent. Healthcare workers, particularly women and those of Asian descent, reported significant challenges with oversized gowns, ill-fitting masks, and gloves that hindered their ability to perform essential tasks (Berg, 2021; Regli, Sommerfield, & von Ungern-Sternberg, 2021). During the pandemic, healthcare workers made tremendous sacrifices to care for those who were sick. Given this, it was shocking to learn that, while on the frontlines risking their lives, they were not only battling a deadly virus, but also struggling to find properly

fitting PPE. This not only affected the quality of care they could provide, but also increased the risk of infection for themselves and all those around them.

Furthermore, the pandemic acts as a great example of how the male form has often been considered the default. The 'universal fit' masks, designed primarily with male facial anthropometry in mind, frequently did not provide adequate protection for women and individuals with more petite facial features (Porterfield, 2020). This highlights a systemic bias somewhere in the PPE design or distribution process, where the needs of a significant portion of the population are overlooked in favor of a presumed 'standard' that, in reality, is far from universal. This paper argues that COVID-19 PPE fit disparities resulted from the interwoven social and technical structures, which prioritized mass production and male-default design, overlooking diverse healthcare worker needs. It will analyze PPE sizing, barriers to access, production prioritization, and government influence by utilizing the Social Construction of Technology (SCOT) framework to demonstrate how the concept of universal fit ultimately failed, leaving many workers vulnerable.

Literature Review

Research has shown that properly fitting masks and PPE were crucial in preventing the spread of the COVID-19 pandemic. It was estimated that asymptomatic individuals were responsible for over half of the COVID-19 transmission (Johansson et al., 2021) and that cotton, surgical, and N95 masks all helped limit virus transmission when worn by someone infected with SARS (Ueki et al., 2020). Masks were especially important as studies concluded that infected individuals were particularly contagious in the 1-2 days before symptoms began, meaning that the only way to fully protect those around you was to be vigilant with the use of PPE (CDC, 2024). Additionally, guidelines put forth by the CDC recommended the use of several types of

PPE to prevent the transmission of COVID-19, including face masks/respirators, face shields, goggles, gloves, and gowns (CDC, 2020).

Proper fit of PPE and masks was known to be essential in preventing the spread of COVID, yet various sources have shown that PPE equipment was not sized to fit different demographics well. The problem of improperly fitting respiratory equipment was brought to attention as early as 2010 when NIOSH found significant differences in facial dimensions that would be important for mask design (Perez, 2023). Since then, several studies have shown that masks that are supposed to be universally sized are significantly less likely to fit women than men, with an even worse fit for women of East Asian descent (Perez, 2023). During the COVID-19 pandemic, when airborne transmission via aerosols was a significant concern, proper protection against aerosol-generating procedures like ventilation was critical. Effective protection could only be ensured if respirators adequately fit a user's facial characteristics, preventing the inhalation of these infectious aerosol particles. Consequently, it is recommended that users do 'fit checks' before use, where masks are inspected for air leakage. Initial fit pass rates are between 40%-90% and are especially low with female and Asian healthcare workers (Regli et al., 2021). Additionally, the improper fit extends beyond just women to include elderly and thin users whose features aren't traditionally masculine. Using computer modeling of facial data, it was found that masks were often oversized on smaller faces, hung off the face near the chin, and could cause more leakage (Mediacorp, 2020).

Feedback from female healthcare workers involved complaints about how "gloves were too big, their face shields caught on their breasts, they were tripping over their gowns and gloves, and their masks were giving them sores (from being pulled so tight to fit) and obscuring their vision (because they were so big on their face)" (Perez, 2023). One female doctor shared her

experience of delivering babies during the COVID era, stating that the gowns were way too big, and it took her several tries to find an N95 respirator that fit her face, which they ended up running out of. She emphasizes that the experience of improperly fitting PPE also increases the stress that healthcare workers experience (Berg, 2021).

Given the huge surge of hospital patients and the severity of the outbreak, the scale of PPE use was greater than what the United States had seen in many years. An article in March 2020 stated that since the start of the pandemic, prices have increased and surgical masks, N95 respirators, and gowns have increased by factors of 6, 3, and 2, respectively (WHO, 2020). This price increase alone would make PPE less accessible to hospitals and healthcare workers. Not only was the scale of PPE use greater in hospitals, but panic buying of face masks and respirators by everyday citizens made it harder for healthcare workers to get the supplies they needed (Lacina, 2020). To help address the increased need for PPE and the difficulty of getting it, the Defense Department's COVID-19 Joint Acquisition Task Force became involved in the management of PPE production, and the Department of Defense (DOD) made investments to help ramp up domestic production. Before the pandemic, the U.S. used about 50 million masks a year, but due to urgent demand, the target domestic production was estimated to be over 1 billion per year by the start of 2021 (Lopez, 2020). Estimate statistics show that the actual use of masks reached over 378 billion in 2020 and 202 billion in 2021 (Richter, 2023).

With the scale of PPE production and use established, to get a full understanding of the scenario, it is vital to take into account the demographic composition and experiences of the healthcare workers who relied on this equipment. According to the Department of Health and Human Services, while women represent 46.9% of the employed population, they account for over 87% of the registered nurses from 2018-2022. Both white women and Asian women are

overrepresented in the healthcare field. Furthermore, while Asian workers comprise 6.1% of the population, they account for 8.3% of personal care aids, 9.3% of registered nurses, and 21.6% of physicians (U.S. Department of Health and Human Services, 2024). These healthcare workers risked their safety and their families' safety to help those who were sick. A survey from the Washington Post showed that 8 out of 10 frontline healthcare workers were concerned about exposing others in their household, and a majority stated that PPE shortages were a source of stress (Kirzinger, Kearney, Hamel, & Published, 2021).

Considering all of these statistics, and knowing that healthcare workers were not adequately protected, it is evident that there was a disconnect in the design, manufacturing, or distribution systems of PPE. Previous research has highlighted the inherent challenges of maintaining an adaptable supply chain, one that is resilient and can quickly respond and optimize in response to changes in supply and demand (Thomas, 2024). Even prior to the COVID-19 pandemic, supply chains were under stress due to political unrest, weather-related emergencies, and other global events (Jenkins, 2024). These already existing vulnerabilities were only heightened when the demand for PPE experienced a major spike. At the same time, consumers were mass buying products like food and toilet paper, many countries were imposing strict border closures, and workers were forced to stay home due to health guidelines or sickness (Moosavi, Fathollahi-Fard, & Dulebenets, 2022). In addition to major supply chain disruptions, it is known that there were pre-existing problems with gendered PPE design. Notably, the problem of ill-fitting PPE for women extends beyond the medical field, affecting construction workers, firefighters, and miners well before the pandemic occurred (Botha & Cronje, 2015; McQuerry, Kwon, & Johnson, 2019; Onyebeke et al., 2016). While these factors demonstrate the scope of

the problem, more analysis needs to be done to determine what specific social and organizational structures contributed to the PPE fit disparity during COVID-19.

I will analyze my research question using the Social Construction of Technology (SCOT) framework to show how various social groups (healthcare workers, manufacturers, government agencies, etc.) influenced the design, production, and distribution of PPE during COVID. In this framework, technologies are not neutral but have 'interpretive flexibility' where they are instead shaped by the interpretations, values, and principles of relevant social groups (Pinch & Bijker, 1984). Relevant social groups refer to sets of actors that share a common interpretation of a technology, its perceived flaws, and desired functionality. In the context of the COVID-19 pandemic, key relevant social groups include healthcare workers, PPE manufacturers, government agencies, hospitals, etc. These groups will be referenced frequently throughout the paper, as understanding their dynamics and relationships with PPE will help reveal how disparity was created. Additionally, stabilization/closure is an important concept in the SCOT framework and occurs when a dominant version of a technology emerges from the various designs that may be preferred by different social groups. The concept of 'universal fit' PPE can be seen as an attempt at stabilization, but instead, it revealed a lack of consideration for many healthcare workers.

In my paper, the goal is to emphasize how the wants and needs of various groups shape what the design of a technology looks like. SCOT will help explain how social factors, as opposed to purely technical aspects, shaped the development and distribution of PPE. Additionally, in this scenario, the power and influence of the different groups play a role in deciding which social group perspectives contributed the most to PPE.

Methods

I will be treating my topic as a case study in an attempt to understand the specific social factors and decisions that led to a PPE disparity. While my research question is meant to be extrapolated to shine light on many disparities that are caused by medical technology, it will be bound to the COVID-19 pandemic in the United States. My primary sources will be government mandates, reports and press releases from manufacturers, and demographic and survey data on healthcare workers. Secondary sources include literature reviews, news articles/reporting on COVID and the experience of marginalized healthcare workers, and technical papers talking about systems of mask production and distribution. Some of the major suppliers of PPE during the pandemic were Honeywell, 3M, and Kimberly-Clark (Halley, 2020). However, this report will mainly focus on 3M, as their publications with manufacturing information were readily accessible, organized, and informative. This review will examine different sources to understand how social systems and the organization of relevant social groups led to PPE disparity.

Analysis

Existence and Availability of PPE Sizing

The first step in determining why there was a lack of properly fitting PPE is to ask what kind of sizing for PPE even existed. It turns out that manufacturers produced a range of PPE sizes, however, the reality on the ground for healthcare workers revealed significant barriers to accessing appropriately fitting equipment. It was found that companies like 3M have different products and fit testing guides for various face sizes, and that fit testing was mandated back in 2004 (Occupational Health and Environmental Safety Division, 2004). In fact, during the pandemic, these Occupational Health and Safety Administration (OSHA) guidelines mandating fit testing for respirators were also listed by the CDC on their website (CDC, 2021). When 3M

was analyzed in more detail, a chart was found with all their different mask designs, including a 'vflex' one that was designed for smaller faces (3M, 2018).

While these masks did exist, there were no posted dimensions, and instead, 3M emphasized the importance of fit testing to determine the correct size mask. To help with sizing, websites like projectN95.com have attempted to create mask size guides, allowing users to read and leave product reviews that include "face size, shape, and any features that have made it hard for you to find a mask in the past" (ProjectN95, 2024). The website includes specific guides for people with small or large faces, kids, and those with low nose bridges, sensory discomfort, etc. Size disparity also occurred in other PPE, including gowns, where one survey showed that 62% of respondents wore either large or one-size-fits-all gowns, and 60% of them stated that they were too big, posing a tripping risk or other hazards. Additionally, while many sizes of gowns do exist, sleeves were often too long, with 81% of the complaints coming from female nurses (The Pandemic and Beyond, 2025). If different options were available from PPE manufacturers and such an emphasis was put on fit testing, why were those with petite, non-masculine, or non-caucasian facial features still not provided with proper fitting PPE?

Barriers to Access

Beyond the mere existence of various PPE sizes, social and organizational barriers, including supply chain disruptions and procurement practices, limited healthcare workers' access to actually receiving properly fitting equipment. First off, the pandemic exposed critical supply chain vulnerabilities, with "98% of hospital leaders said the pandemic exposed significant supply chain vulnerabilities in their hospitals" (Nadeau, 2023). This resulted in dramatic price spikes, such as a 2000% increase for isolation gowns and over 6000% for 3M N95 masks between March and April 2020. Even seven months into the pandemic, nearly 70% of facilities reported

PPE inaccessibility, forcing some healthcare workers to reuse equipment (Hannah, 2021). Because there was not enough PPE to go around in the original networks, hospitals had to expand their search for products. Websites to help organize donations to hospitals were created, highlighting the dire need for supplies (DonatePPE, 2020). Compounding these issues was a lack of effective communication and feedback loops. State officials struggled to secure PPE from both domestic and international suppliers (Handfield, 2020), and hoarding by less-affected hospitals contributed to shortages. Moreover, missing supply chain data is a common problem that emerges from a mindset in the market where competitors do not want to share data in fear of revealing information or being at a disadvantage. The lack of information and publication of data can create a scenario where "both suppliers and customers point to each other as the source of the problem" (Handfield, 2020). Additionally, with data like the exact breakdown of different sizes and types of masks manufactured being inaccessible, retrospectively analyzing the situation becomes difficult.

Production Prioritization and Males as a Default

Although the supply chain disruptions and barriers to access help explain why there were critical shortages of PPE, they fail to explain why the PPE that was received did not fit its users. While the technical factors and systems surrounding PPE distribution and procurement contributed to the PPE disparity, perhaps more important were the underlying social norms involved. Systemic gender bias, embedded in product design and manufacturing, likely influenced production prioritization, leading to a disproportionate focus on 'universal fit' PPE that primarily accommodated male anthropometry. Inherent bias led to the unavailability of smaller sizes, not because smaller sizes of masks did not exist, but instead because of a significant imbalance in production quantities. Regardless of the realm of the product being

talked about, anthropometric data collection has historically been centered on men. One article talking about gender bias in medicine states that the male body has been treated as the "biological default" (Bartlett, 2024). This concept helps explain why, even though smaller masks that better fit women's faces existed, when it was time for production to ramp up, the model that was produced the most was the 'universal fit' model which worked better with caucasian, male features.

Nursing is one of the very few fields where we see women overrepresented in the workforce. Almost 90% of all registered nurses in the United States are female (Yang, 2023). Given a distribution like this, a greater focus on PPE sizes and designs that accommodate female anthropometry should have been taken by both producers and hospitals. As mentioned before, even hospital gowns, which have a lot simpler sizing than masks, were not available in the proper sizes. This demonstrates that there was a failure in either the production of correct sizes of PPE or the ordering of PPE by hospitals. However, given that most hospitals were desperate to get their hands on any PPE, we can assume that at least part of the issue stemmed from the type of PPE that was selected to be mass produced. This is where the failure in SCOT stabilization occurred. While the universal fit model emerged as the dominant technology that was mass produced, it failed to adequately protect a large portion of its users.

The concept of a universal fit is, at its core, biased. Masks, gowns, and other PPE that were advertised as having a universal fit and were mass-produced did not actually fit all of their users. The problem is that unisex PPE is often on the larger side and is too big for many female healthcare workers (Porterfield, 2020). A common counterargument in support of unisex PPE is the 'better too big than too small' claim. While seemingly logical, this concept masks a deeper bias that disproportionately affects women. This is a recurring theme that can be found across

engineering, with one example involving vehicles. On average, women sit closer to the steering wheel because they are shorter (McFadden, Powers, Brown, & Walker, 2000). The close proximity can put them at an increased risk of injury via the steering wheel/airbag, as the National Highway Traffic Safety Administration (NHTSA) recommends keeping at least 10 inches between the steering wheel and the chest (NHTSA, 2025). Cars that are built on the larger side make this nearly impossible for shorter women. The same concept can be applied to oversized PPE, while those who are petite can still wear bigger PPE, it will be uncomfortable and put them at a higher risk of air leakage and therefore infection. This is the exact same outcome that would occur if a larger person were to try and use smaller PPE; the fit might not be perfect, and the infection risk could be increased. If the outcomes are the same, why is the default choice to mass-produce larger sizes of PPE when so much of the medical workforce was comprised of women who would likely have benefited from smaller PPE? Well, besides the lack of communication between medical workers, hospitals, and manufacturers, the situation of the pandemic itself contributed.

Urgency of Speed and Government Influence

Because of the tremendous scale and unprecedented nature of the pandemic, the pressure to rapidly produce and distribute PPE, combined with government guidelines, contributed to the observed discrepancies in fit. In April 2020, the Federal Emergency Management Agency (FEMA) issued a Defense Production Act (DPA) that ordered 3M and other manufacturers to prioritize governmental orders to increase and provide N95 masks. This created significant pressure on the producers (FEMA, 2021). In addition, the government outlined extreme mask production goals that undoubtedly created a sense of urgency around mask production given the sheer volume of demand (Cohen & Rodgers, 2020). To meet the demand, companies like 3M had to leverage new technologies for things like recruitment and training, balancing remote work and social distancing with the extreme need for PPE. They also had to automate more of their production and inspection under rapidly evolving constraints (Manufacturing Leadership Council, 2020). The national shortages of PPE led to hospitals and healthcare workers being forced to adopt an "anything is better than nothing" ideology. It was not uncommon for PPE to be improvised during shortages, with the CDC even releasing information on homemade masks. 3D printing companies were also releasing designs to help people make their own face shields. (American College of Healthcare Executives, 2020; Prusa3D, 2020).

Given the extent of the pandemic, the demand manufacturers were under, and the added pressure from governmental orders, it is not surprising that there was a shortage of PPE, but the question remains as to why there was specifically a shortage in PPE that fit women. Due to the desperation for PPE and the rush for production and distribution, there was a decrease in quality control. One case demonstrating this involved the U.S. having to recall 9 million surgical gowns that were not properly sterilized, thus forcing some caregivers to wear trash bags, raincoats, or other alternatives in an attempt to protect themselves (Sanders, 2020). Looking at situations like this, it is not hard to imagine that the decrease in quality control might have also resulted in a decrease in attention to sizing and a reliance on default 'universal fit' designs. The entire situation was exacerbated by a significant communication breakdown between manufacturers, hospitals, and healthcare workers. The chaotic environment of the pandemic severely limited feedback loops and the time available for fit feedback between users and manufacturers to occur and be taken into consideration.

Conclusion

This case study has shown that the PPE fit disparities experienced during the COVID-19 pandemic were not just an oversight, but rather a result of the social, technical, and organizational structures that went into the manufacturing and distribution processes. By looking into key relevant social groups like healthcare workers, manufacturers, and hospital leadership, a clearer picture could be painted of the complicated nature surrounding PPE access. Healthcare workers, a mostly female population, shared their experiences with missized PPE confirming that even though smaller PPE sizes existed, for some reason, they did not have access to them. While this could be due to sizing discrepancies in hospital orders, because hospitals were fighting for any PPE, it was likely due to the growth in popularity of the 'universal fit' design. It was probably easier and faster for manufacturers to ramp up production on a generic model and not fully consider the ramifications or demographics of the end users. Universal fit masks were not optimized for female or Asian healthcare workers like they were for caucasian males, an action that ignored the interpretive flexibility of 'fit' among different social groups. Supply chain disruptions and hospital procurement strategies, along with communication breakdown between manufacturers, distributors, and healthcare workers, contributed to the struggles of sourcing the needed PPE.

Moving forward, it is essential to establish strong feedback mechanisms and ensure that relevant social groups, particularly those historically marginalized, are actively considered and included in the PPE design, manufacturing, and distribution processes. This will require a shift from a 'universal fit' mentality to a more nuanced approach that acknowledges and accommodates the diverse needs of all users.

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