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## The Personal Protective Equipment as a Hazard: Review of the Respiratory Protective Equipment as a Case Study

<sup>1\*</sup>Towolawi, A. T., <sup>2</sup>Bamigboye, T. L., <sup>3</sup>Taiwo O.A., <sup>1</sup>Adegbite, K. I., <sup>1</sup>Oladeji, F. O., <sup>5</sup>Adegoke, J. I., <sup>2</sup>Adeleke, E.A., <sup>2</sup>Olaboopo, M. O., and <sup>4</sup>Umar, N. J.

<sup>1</sup>Department of Environmental Health Science, Fountain University Osogbo, Osun State, Nigeria; <sup>2</sup>Department of Nursing Science, Fountain University Osogbo, Osun State, Nigeria; <sup>3</sup>Department of Nursing Science, Adeleke University, Ede, Osun State, Nigeria; <sup>4</sup>Department of Nursing Science, University of Ilorin, Ilorin, Kwara State, Nigeria, <sup>5</sup>Department of Nursing Science, Osun State University, Osun State, Nigeria.

### Abstract

Occupational safety globally envisioned maximum performance and prevention of workforce shortfall of the nurses and health workers via the United Nations' Sustainable Development Goal 3: good health and well-being, and the International Council of Nurses' view encapsulated in the Nursing Personnel Convention of 1977 (No. 149). The review used relevant journal articles to present the concept of respiratory personal equipment (RPE) starting with its types, which are either air-supplying respirators (*supplied-air respiratory system*: used in biosafety level four laboratories that deal with highly infective agents and *self-contained breathing apparatus*: used by special personnel who work in oxygen-deficient environments) or air-purifying respirators (*non-powered*: filtering facepiece masks and elastomeric respirators and *powered*). The potential hazards of the RPE were presented to include physical discomfort and health issues, where rebreathing of the expired air increases arterial CO<sub>2</sub> levels with the chances of blood acidic elevation, and obstructive pulmonary disease; skin irritation and allergic reactions; compounding heat stress; psychological effects with emotional stress and communication barriers; and impairment of senses with vision obstruction and hearing impairment. Improper use and maintenance with fit and seal issues, contamination risks, and misuse and overreliance were determined to turn the RPE into a hazard with real-world cases to establish how RPE can be a hazard. The review gathered improving RPE design and comfort, training programmes, maintenance and hygiene, and policy and administrative controls as the strategies to mitigate the associated risks of using RPE, which occupational safety views as an inevitable PPE.

**Keywords:** arterial CO<sub>2</sub>, obstructive pulmonary disease, occupational safety, respirator, SDG 3

### INTRODUCTION

Personal Protective Equipment (PPEs) have been widely recognized and accepted as a tangent component of occupational safety due to their role in safeguarding workers and professionals from hazards that may ensue during their work schedule. The PPEs consist of a wide range of

materials including helmets, respiratory protective equipment (RPE), face masks, gloves, eye protection, boots/shoe covers, and aprons.

\*Corresponding Author: +234 806 017 2946

Email address: [taofiktowolawi@yahoo.com](mailto:taofiktowolawi@yahoo.com)

The increasing acceptance and use of PPEs can be attributed to the growing emphasis on worker safety regulations and the increasing awareness of occupational hazards. It can also be attributed to the recent world events such as COVID-19, which emphasized the protective roles and potential drawbacks of the used/ disposable PPEs.

The empirical studies delved into knowing some considerable factors that have to do with the RPE effectiveness for their real-world usage. The premier factor is the level of the hazard-risk determination from the penetration and inhaled-dose, considering the particle aerodynamic features (such as the density, shape, and size), drifting rate, and filter type, especially at the occupational niche (Huang *et al.*, 2013); the associated problem is the materials' filtration efficiency to differentiate between the ambient air and biological dispersion (Good *et al.*, 2021). The second factor dwells on device breathability for comfort, intact, and ventilation on the wearer (Johnson, 2016; Leith *et al.*, 2021). The third factor is about the protecting fitness across the workplaces under various requirements that include gender, facial shape, and individual perspiration (Kim *et al.*, 2016; Coffey & Miller, 2019). The fourth factor encompasses bio aerosol deposition and multiple usage associated issues which respectively calls for treatment and disinfection (Jachowitz *et al.*, 2019; Sankhyan *et al.*, 2021). The fourth and last point clinches on adoptability approach for the wearers to unanimously embrace the RPE usage; enforcement (Sprengholz *et al.*, 2020) or encouragement (Fischer *et al.*, 2021). However, either of the two approaches have to win the wearers' knowledge (Sikakulya *et al.*, 2021), attitude, practices, and cultural norms (Casola *et al.*, 2021). However, recent research suggested that the use of PPEs can introduce unforeseen hazards, transforming the envisioned safety net into a potential double-edged sword (Sehsah *et al.*, 2020). The focus of this review study was to look into the hazards that utilizing respiratory protective equipment (RPE) brought about and ways to lessen, manage, and avoid the associated risks from leading to severe and permanent disability; this made the general

objectives of the study to identify the specific hazards associated with RPE; present the real-world cases, where the hazards had manifested; and propose strategies to mitigate these risks.

## CONCEPT OF THE RESPIRATORY PROTECTIVE EQUIPMENT

### Types of Respiratory Protective Equipment

Respiratory protective equipment is divided into two groups: air-supplying and air-purifying respirators (Fig. 1) (Cobanoglu *et al.*, 2020).

#### Air-supplying respirators

Air-supplying respirators are specially designed devices that provide clean breathing air to the wearer and isolate the wearer from the environment's atmosphere; they can be used in oxygen-deficient environments or against airborne hazards (toxic fumes) and infectious agents with the highest respiratory safety level. There are two types of air-supplying respirators: supplied-air respiratory system and self-contained breathing apparatus. The former (supplied-air Respiratory System) provides clean and breathable air to the wearer from an air supply through an airline and is especially used in biosafety level four laboratories that deal with highly infective agents such as the Ebola virus, the Marburg virus, or the Lassa virus. The latter (Self-contained Breathing Apparatus) utilises clean and breathable air from a tank that is generally carried by the wearer and is used by special personnel who work in oxygen-deficient environments or are exposed to highly toxic and hazardous fumes.

#### Air-purifying respirators

Air-purifying respirators are different types of masks and devices that can clean the environment's air, thereby protecting the wearer from airborne hazards and infectious agents, they are widely used in medical applications, particularly during the COVID-19 pandemic. Air-purifying respirators are divided into two groups according to power supply: non-powered and powered.

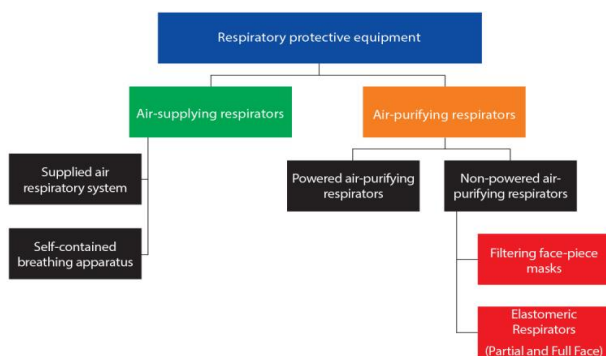


Fig. 1: The classification of respiratory protective equipment

The former (non-powered air-purifying respirator) does not require any power supply. However, all wearers should undertake “respirator fit-testing” before usage. There are two types of non-powered air-purifying respirators: filtering face piece masks (Plate 1) and elastomeric respirators (Plate 2); the filtering face piece masks were classified based on their filtering performance of the particles  $> 0.3 \mu\text{m}$  as FFP1, FFP2 and FFP3 defined as  $> 80$ ,  $> 94$  and  $> 99\%$ , respectively, while the elastomeric respirators (partial or full-face) were originally designed for pest control companies and started to be used during surgeries or high-risk procedures during the pandemic. They have good respiratory protection with easy breathing when relatively compared with FFP masks. The powered air-purifying respirator (Plate 3) filters contaminants in the air using a battery-operated blower to maintain clean air for the user through a tight-fitting respirator; which is either a loose hood or a helmet. It is specific for high-hazard procedures and usually has a full facepiece part and loose-fitting hoods attached to waist-mounted belt batteries.

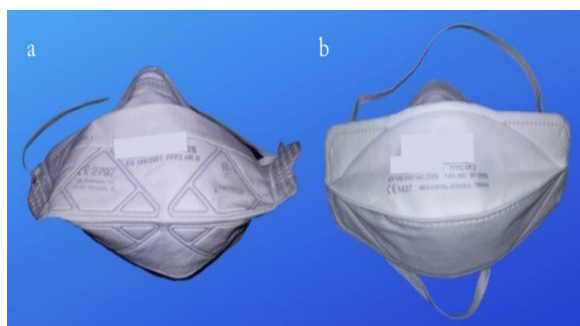


Fig. 2: Filtering face piece masks (a) FFP2 ( $> 94\%$ ) and (b) FFP3 ( $> 99\%$ )



Fig. 3: Elastomeric respirators (a) partial-face, (b) full-face



Fig. 4: Powered air-purifying respirator

## THE GOODS AND HAZARDS OF RESPIRATORY PROTECTIVE EQUIPMENT

### Good Side of the Respiratory Protective Equipment

As the name says, respiratory protective equipment (RPE) shields its wearer from potentially harmful compounds in the surrounding air. The RPE is any mask or device designed for the protection of the wearer from different airborne hazards and infectious agents. Its capacity to lower the risk of respiratory illnesses and infections is one of its main advantages. The use of the masks, especially the N95 respirators, proved to be quite successful in stopping the spread of SARS-CoV-2 among medical personnel and the general public during the COVID-19 epidemic. Certainly, the key parameter that determines the efficiency of RPE is the maintenance of secure fitting (sealing) along the face line while being used. The efficiency of respirators and their air-tightness for inhalation and exhalation are evaluated using the fit test with

aerosol indication; their valves open only during exhalation, allowing free air release. The presence of an exhalation valve prevents the fogging of glasses, which is important for medical personnel (Lukanina *et al.*, 2021). According to a study carried out by Chu *et al.* (2020), it was discovered that the consistent use of face masks combined with other preventive measures markedly decreased the incidence of COVID-19, underscoring the vital role of RPE in infection control. In industrial settings, RPE serves as a crucial line of defence against hazardous substances such as dust, fumes, vapours, and chemical aerosols. The RPEs have been instrumental in improving occupational health issues by mitigating the long-term effects of exposure to toxic substances; prolonged exposure to harmful airborne agents can lead to chronic respiratory conditions, including asthma, bronchitis, and even lung cancer.

### **Potential Hazards of the Respiratory Protective Equipment**

Despite being regarded as a crucial tool used in protecting workers from airborne-related hazards and highly regarded personal protective equipment, the RPE is not without its setbacks. Even though it was designed to protect the wearer from harmful substances, it can also introduce a range of hazards that complicate its use and efficiency. Understanding such hazards is essential for ensuring that the RPE provides the intended protection without compromising the health and safety of the wearer.

#### **Physical discomfort and health issues**

##### ***Fatigue and breathing resistance***

It has been suggested that long-term use of the N95 mask with protective eye gear might lead to entrapment of exhaled moisture in the filters, resulting in increased breathing resistance. Meanwhile, the face mask represents a closed circuit for the inspired and expired air; rebreathing of the expired air increases arterial CO<sub>2</sub> levels and raises the chances of elevated acidity of the blood. Any healthcare professional working with a N95 mask may experience signs similar to those shown

in patients with chronic obstructive pulmonary disease such as discomfort, headache, shortness of breath, fatigue, dizziness, muscular weakness, and drowsiness (Hussain *et al.*, 2022).

##### ***Skin irritation and allergic reactions***

Studies have demonstrated the negative dermatological impact of prolonged mask-wearing on healthcare workers as the surgical mask (including the N95 mask) led to erythema, papules, pustules, acneiform eruptions, acne mechanical, pigmentation, and purpuric changes along the line of attachment of the mask, urticarial eruptions and contact dermatitis to metals, formaldehyde, and other preservatives (Das *et al.*, 2020).

##### ***Compounding the heat stress***

Healthcare workers wearing PPE has become a common phenomenon since the advent of coronavirus disease 2019 (COVID-19), whose outbreaks overlapped with heat waves, and healthcare workers must, unfortunately, wear PPE during hot weather and experience excessive heat stress (Zhu *et al.*, 2023). The PPE severely hinders heat exchange owing to sweat evaporation because of the high level of protection required. The state of healthcare workers approximates a thermodynamically closed system with neither molecular nor a very limited energy transfer between the wearer and the external environment when wearing respiratory protective equipment. Such experiences result in a significant reduction in wearers' heat loss, thereby severely affecting their productivity and health in hot weather and increasing the risk of compounding heat stress (Mao *et al.*, 2022).

#### **Psychological Effects**

##### ***Emotional distress***

Healthcare workers caring for COVID-19-infected patients were exposed to stressful and traumatic events with the potential for severe and sustained adverse mental and physical health consequences. Hospital staff who treated COVID-19 patients reported a high prevalence of emotional distress and serious physical discomfort

due to prolonged PPE usage (Candido *et al.*, 2023). Bierman *et al.* (2021) reported negative impacts (e.g., increased levels of anxiety, depression, and psychological distress) on the psychological health of the wearer and those who interacted with them.

### **Communication barriers**

The RPE such as filtering facepiece respirators, elastomeric respirators and powered air-purifying respirators are routinely worn in the critical care unit as a PPE component when caring for patients with the coronavirus disease 2019. However, the RPE may inadvertently interfere with verbal communication between critical care staff (Round and Isherwood, 2021); this can lead to misunderstandings and errors, particularly in an environment, where clear communication is critical for safety and operational efficiency. Miscommunication can not only interrupt workflow and lower work efficiency but also lead to misunderstandings and workplace conflicts (Leung *et al.*, 2022).

### **Impairment of Senses**

#### **Vision obstruction**

When selecting a respirator, it is important to understand how employees' motor, visual and cognitive abilities are impacted by the PPE. Visual information from the lower peripheral field is important for detecting and avoiding nearby hazards and for safely placing steps; wearing a face mask reduces the wearer's opportunity to use this important sensory information during walking and may therefore increase the chance of tripping or falling (Kal *et al.*, 2020).

#### **Hearing impairment**

There is potential for any PPE used on the face or head to impact social interaction and cognition (e.g., hearing protection) and therefore, act as a psychosocial hazard or stressor (Leung *et al.*, 2022).

### **Improper Use and Maintenance**

#### **Fit and seal issues**

The key parameter that certainly determines the efficiency of RPE is the maintenance of secure fitting (sealing) along the face line in the course of use (Lukanina *et al.*, 2021).

#### **Contamination risks**

The practice of reusing PPE poses high levels of risk for accidental contamination by healthcare workers, who became infected while caring for patients due to errors in the use of PPE; this represents a serious occupational risk to HCWs from reusing an N95 respirator because of the high risk of self-contamination and infection (Doos *et al.*, 2022).

#### **Misuse and overreliance**

Overreliance can lead to complacency in implementing other critical safety measures, such as ventilation and administrative controls. Workers and employers may mistakenly believe that RPE alone is sufficient, creating a false sense of security and increasing the overall risk of exposure to hazards. It is essential to integrate RPE use into other PPE strategies to ensure all-inclusive safety.

### **HIERARCHY OF CONTROLS**

The hierarchy of controls is a framework employed in occupational safety and health to understand the relative effectiveness of different strategies for risk reduction and help determine how to implement feasible and effective solutions (Sehsah *et al.*, 2020). PPE is used by workers across industries to reduce health and safety hazards exposure, yet the use of PPE is recognized as the last step in the hierarchy of control to mitigate occupational hazards and the least effective measure of controlling the associated risks (Olaru *et al.*, 2021). The hierarchy progresses from the elimination of the hazard, through substitution, engineering, and administrative measures, down to PPE usage (Fig. 2). Although PPE has its limitations, its use is still considered

an important protective barrier considering other higher-order control methods. Hazard exposure cannot be adequately reduced in emergency response scenarios more than PPE (Leung *et al.*, 2021). The most effective hazard controls, elimination and substitution, involve physically removing the hazard and associated risk or substituting the hazard with something less risky. As a precautionary measure, eliminating unnecessary public outings or gatherings is another effective means of removing the risks such as the SARS-CoV-2 infection. Similarly, allowing remote work or moving indoor activities outdoors substitutes the hazards incumbent on in-person activities with less risky alternatives (Sehgal *et al.*, 2021).

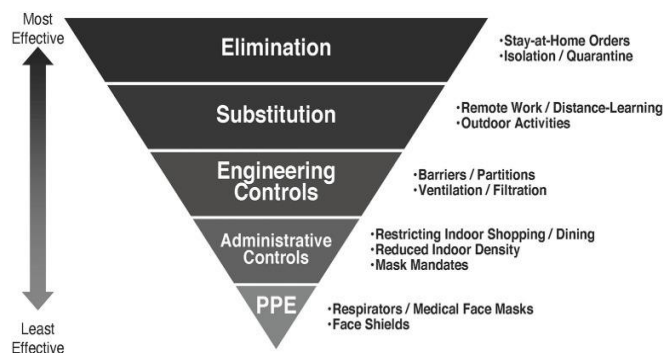


Fig. 5: The hierarchy of hazards' and associated risks' controls.

Engineering controls do not eliminate hazards but isolate individuals from them and their associated risks. Well-designed engineering controls can be highly effective, reducing risk to individuals independent of their behaviours, and significantly enhancing protection for individual adherence to administrative controls or employing PPE (Sehgal *et al.*, 2021).

Administrative controls involve changing individual behaviours via policy or mandate to minimise hazards and the associated risks. The controls are the most frequently instituted to increase social distancing, and reduce person-to-person interaction or population density in defined spaces to protect against infection (Sehgal *et al.*, 2021).

The final hazard and associated risk reduction strategy is the employment of PPE,

protecting individuals from known hazard exposure using respirators, eye protection, and other individually donned protective items. The PPE can reduce hazards and the associated risks, though it is necessarily less protective than controls higher in the hierarchy (Sehgal *et al.*, 2021). Thus, it is essential to integrate multiple levels of controls to effectively manage workplace hazards; this layered approach ensures that if one control measure fails, others remain in place to provide protection. For example, in managing hazardous chemicals exposure, an organization might eliminate the use of the most dangerous chemicals where possible; substitute the hazardous chemicals with safer alternatives; implement engineering controls such as fume hoods or enclosed systems to contain the chemicals; develop administrative controls by training workers on safe handling procedures and limiting exposure time; or lastly provide relevant PPE such as gloves, goggles, and respirators as a last line of defence.

## CASE STUDIES

Examining real-world applications of the RPE through case studies provided valuable insights into its benefits and potential hazards. The following two case studies illustrate how RPE has been used in various settings.

**Healthcare during the COVID-19 Pandemic:** During the COVID-19 pandemic, healthcare workers were at the forefront of the battle against the virus, making the use of RPE crucial in preventing the spread of infection. The healthcare workers employed PPE during the COVID-19 pandemic, which was crucial to protecting themselves from infection wearing of PPE, especially facial masks, was necessary among healthcare workers, while training on the proper use of PPE was also important to prevent infection (Soleman *et al.*, 2023). Chu *et al.* (2020) found that consistent use of face masks with other preventive measures markedly decreased the incidence of COVID-19 in healthcare settings, thereby having the outcome that wearing PPE protects healthcare workers from COVID-19 infection among healthcare workers. The

inevitable challenges were sought include **supply shortages**; although they were not intended for reuse, the scarcity of these materials during the pandemic is a known challenge (Cubas *et al.*, 2023); and **fit and comfort issues**: prolonged wearing of tight-fitting respirators led to discomfort, skin irritation, and fatigue among the healthcare workers. The absence of secured fitting between the wearer and the equipment significantly reduced the effectiveness of the equipment and posed impending hazards.

**Workers in chemical manufacturing companies:** Workers in chemical manufacturing companies are exposed to various hazardous substances, including toxic gases, vapours, and aerosols; this made RPE a critical component of the safety protocols in these environments. The RPE is the last resort to control exposure to workplace air pollutants. A comprehensive respiratory protection programme (RPP) ensures that RPE is selected, used, and properly cared for. Therefore, RPP must be well integrated into the occupational health and safety requirements (Kolahi *et al.*, 2018). The outcome is that when properly used, RPE has significantly reduced the exposure of workers to harmful chemicals and decreased the incidence of occupational illnesses. **The inevitable challenges** required **training and fit-testing** to ensure that all workers are adequately trained and streamed to undergo regular fit-testing against logistical challenges for the effectiveness of RPE.

## MITIGATION STRATEGIES

The mitigation strategies that may be considered in managing hazards associated with the use of RPE include:- **Improving RPE design and comfort:** ergonomic design; manufacturers should focus on creating RPE that offers better ergonomic features, including improved fit, lighter weight, and materials that minimize skin irritation; **Enhanced breathability:** developing respirators that allow for easier breathing can significantly reduce the discomfort associated with breathing resistance. A “panic fitness” evaluation for the use of respirators should be considered in different

settings, including the workplace, and strategies to decrease discomfort should be identified to increase the rate of compliance (Perna *et al.*, 2020). **Comprehensive training programmes:** proper usage training; the RPE only offers protection when properly worn, safely removed and it is regularly replaced or maintained. Training in the proper use of RPE is important to prevent infection (Soleman *et al.*, 2023). According to Zhuang *et al.* (2016), the fit of a mask can be impacted by various factors such as weight loss or gain to require a face fit regular test for individuals. **Maintenance and hygiene:** regular cleaning and inspection; proper cleaning and maintenance is an essential part of ensuring the respiratory masks achieve optimum performance and maximise their lifespan (de Perio *et al.*, 2020). After the respiratory mask has been cleaned and reassembled, it should be stored in a clean and dry place until it is going to be used again. Ideally, the respiratory mask should be in a storage bag or box, which will protect it from light, humidity, damage, and chemicals (Armentano *et al.*, 2021). **Policy and administrative controls:** *Usage Policies;* supervise RPE wearers to ensure that they are using the RPE following the manufacturer's instruction and the training provided, safely dispose of damaged or used RPE and its components, take note of waste handlers' health and safety (Graveling *et al.*, 2011). *Monitoring and Enforcement;* ensure that control measures, including RPE, are properly used and not made ineffective by incorrect work practices or incorrect use. Also ensure that employees use the control measures, including RPE, the way they are intended to be used and as trained (Luong-Thanh *et al.*, 2016). **Integration with other control measures:** combining controls; respiratory protective equipment should be used as part of a comprehensive safety strategy that includes engineering controls, administrative controls, and other protective measures; this multi-layered approach enhances overall safety and reduces reliance on RPE alone (Lea *et al.*, 2022). **Engineering Controls;** implementing engineering controls such as ventilation systems and containment barriers can reduce the need for RPE

by minimizing the presence of airborne contaminants in the first place.

## CONCLUSION AND RECOMMENDATIONS

Respiratory protective equipment (RPE) is essential for protecting employees from dangerous airborne pollutants in a variety of industries. It is clear from thorough case studies in the fields of chemical production, healthcare, and construction that although RPE provides an efficient way against exposure to hazardous compounds, the associated problems including maintenance, supply shortages, and compliant concerns need to be taken into consideration. Thus, organisations can ensure that workers are protected to the highest degree while minimising risks by enhancing the design and comfort of respiratory protective equipment, putting in place thorough training programmes, and maintaining its use with other control measures. The following recommendations should be considered to enhance the effectiveness and safety of RPE in the workplace

- Address psychological and comfort issues
- Ensure proper maintenance and hygiene
- Integrate RPE with other safety measures
- Invest in ergonomic and technologically advanced RPE
- Promote a culture of safety, and
- Strengthen policy and administrative controls.

### Conflict of interest

The authors declare that there is no conflict of interest.

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