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Prospective observational study of gender and ethnicity biases in respiratory protective equipment for healthcare workers in the COVID-19 pandemic

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ABSTRACT

Objective To describe success rates of respiratory protective equipment (RPE) fit testing and factors associated with achieving suitable fit.

Design Prospective observational study of RPE fit testing according to health and safety, and occupational health requirements.

Setting A large tertiary referral UK healthcare facility.

Population 1443 healthcare workers undergoing quantitative fit testing.

Main outcome measures Quantitative fit test success (pass/fail) and the count of tests each participant required before successful fit.

Results Healthcare workers were fit tested a median (IQR) 2 (1–3) times before successful fit was obtained. Males were tested a median 1 (1–2) times, while females were tested a median 2 (1–2) times before a successful fit was found. This difference was statistically significant (p<0.001). Modelling each fit test as its own independent trial (n=2359) using multivariable logistic regression, male healthcare workers were significantly more likely to find a well-fitting respirator and achieve a successful fit on first attempt in comparison to females, after adjusting for other factors (adjusted OR=2.07, 95% CI): 1.66 to 2.60, p<0.001). Staff who described their ethnicity as White were also more likely to achieve a successful fit compared with staff who described their ethnicity as Asian (OR=0.47, 95% CI: 0.38 to 0.58, p<0.001), Black (OR=0.54, 95% CI: 0.41 to 0.71, p<0.001), mixed (OR=0.50 95% CI: 0.31 to 0.80, p=0.004) or other (OR=0.53, 95% CI: 0.29 to 0.99, p=0.043).

Conclusions Male and White ethnicity healthcare workers are more likely to achieve RPE fit test success. This has broad operational implications to healthcare services with a large female and Black, Asian and minority ethnic group population. Fit testing is imperative in ensuring RPE effectiveness in protecting healthcare workers during the COVID-19 pandemic and beyond.

Strengths and limitations of this study

- This was a single-centre study.
- Although the demographics of the workforce observed in our study accurately reflects those of the National Health Service workforce in London (UK), they may not be reflective of the rest of the country.
- A large number of fit tests and participants were observed.
- Each individual did not test on every model of face mask.
- Other factors affecting the fit testing were not investigated or adjusted for.

INTRODUCTION

The COVID-19 pandemic has dramatically affected the delivery of healthcare. Many routine procedures that produce potentially infectious aerosols were previously conducted regularly without protective face coverings, but this is no longer appropriate during the pandemic. Preventing aerosolised spread of infection from patients to healthcare workers relies on effective use of respiratory protective equipment (RPE), including tight-fitting filtering facepiece (FFP) respirators.[1–3] Protection of healthcare workers with suitable RPE must be prioritised as their exposure places them at high risk of contracting infection with COVID-19.[4 5] Critical shortages in the availability of adequate RPE have been highlighted, with healthcare workers from Black, Asian and minority ethnic (BAME) groups being disproportionately affected.[6]

The effectiveness of a respirator depends on a good fit on the healthcare workers' face.[7–9] Although respirators are designed to fit the majority of individuals, no single respirator can provide a universal fit.[8–11] The fit of RPE has been suggested to be unsuitable for women and BAME healthcare workers, however there remains insufficient objective data demonstrating this disparity. There is therefore a need to assess the

ethnodemographic impact on suitability of respirators provided by employers. The purpose of this observational study is therefore to determine if ethnicity and gender are factors in the suitability of respirators in healthcare workers exposed to patients with COVID-19.

METHODS

We conducted a prospective observational study examining fit testing results by ethnicity and gender from staff in a central London teaching hospital and designated COVID-19 centre. No patients or members of the public were included in this study. All members of the workforce in patient-facing roles were eligible to attend the fit testing clinic. We included healthcare workers who underwent quantitative fit tests (QNFT) only. Exclusion criteria were healthcare workers who were not in patient-facing roles, those unable to undertake the fit testing procedure (eg, unable to remove head wear, remove facial hair or physically unable to perform the procedure), those that underwent only qualitative fit testing, or those unwilling to participate in fit testing.

Fit testing data were collected between 3 February and 3 July 2020 and included the participant's self-described gender and ethnicity in free-text. The free-text responses were mapped to the Office of National Statistics categories for ethnicity as used in the UK census.[12]

Fit testing was conducted by certified fit testers. Participants had to refrain from smoking 1 hour prior to the test, had to be clean shaven and could not wear any head wear. The QNFT involved the use of a TSI Portacount 8030 (TSI UK, High Wycombe) using the standard Health and Safety Executive fit testing procedure.[13]

QNFT fit test scores were dichotomised as pass or fail based on achieving an overall fit factor >100. We report the overall numbers and proportions of staff who passed their first fit test and grouped by self-reported gender and ethnicity. The likelihood of passing the first fit test for male and female genders, and White and BAME groups were compared using Pearson's χ^2 test (without Yate's Continuity, as all cell frequencies were greater than 10). Logistic regression modelling was performed using each fit test as a separate observation, with the binary outcome variable defined as fit test success (pass/fail), and using the following explanatory variables: gender, ethnicity and mask design (disposable vs reusable). We first modelled the bivariate association between the outcome variable and each explanatory variable separately, and then in a multivariable model including all explanatory variables to obtain adjusted OR estimates. Mask designs were specified in our models as categorical variables and were compared against a reference design A, which was our most widely tested disposable mask design. The following post hoc analyses were performed to assess the possibility that healthcare workers could learn to game the fit testing process and repeated testing of the same healthcare workers using different masks could render the tests not independent of each other: First we fitted mixed effects logistic regression models with random-intercepts for healthcare workers, assuming that tests were nested within healthcare workers; Second we repeated the original fixed-effects only logistic regression modelling with a subset of our dataset, only including data from first attempt fit tests. The results of the post hoc analyses were compared with our original findings and reported within online supplemental figures A and B. All analyses were performed in Microsoft Excel (Microsoft, Redmond, Washington, USA) and R V.3.5.2 (R Foundation for Statistical Computing, Vienna, Austria). Only records with complete data for the variables modelled (gender, ethnicity, mask design, outcome of fit test) were analysed. Continuous variables are reported as mean (SD (SD)) for normally or uniformly distributed data or median (IQR) for data with skewed distributions. For discrete variables, numbers and proportions are reported. Non-parametric data were compared with the Mann-Whitney U test, and the Student's t-test was used for parametric data. A $p<0.05$ was considered statistically significant.

Table 1 Gender and ethnicity of the staff that underwent quantitative fit testing

	n (%) (n=1182)
Gender	
Male	365 (30.9)
Female	817 (69.1)
Ethnicity	
White	557 (47.1)
Asian	383 (32.4)
Black	175 (14.8)
Mixed	39 (3.3)
Other	28 (2.4)

Patient and public involvement

There was no patient or public involvement in this study.

RESULTS

A total of 1443 healthcare workers underwent fit testing during the study period. After exclusions were applied, a total of 1182 records were available for analysis. The gender and ethnicity breakdowns for the staff members are described in table 1.

Each staff member was fit tested a median (IQR) 2 (1–3) times before a successful fit was found. Males were tested a median 1 (1–2) times and females a median 2 (1–2) times before a successful fit was found ($p<0.001$).

There were 2359 independent QNFTs modelled using logistic regression (table 2). Values are number (proportion) or odds ratio (95% CI). To assess the possibility of non-independence between tests performed on the same healthcare worker, an additional post hoc mixed-effects model fitted with random-intercepts for healthcare workers did not materially change our findings (online supplemental figure A). Similarly, a post hoc fixed-effects only model fitted using only data from first fit

Table 2 Logistic regression models

Dependent outcome: successful fit		Fail n (%)	Pass n (%)	OR (univariable)	OR (multivariable)
Gender	Female	709 (80.8)	1007 (67.9)	–	–
	Male	168 (19.2)	475 (32.1)	1.99 (1.63–2.44, p<0.001)	2.07 (1.66–2.60, p<0.001)
Ethnicity	White	301 (34.3)	721 (48.7)	–	–
	Asian	357 (40.7)	478 (32.3)	0.56 (0.46–0.68, p<0.001)	0.47 (0.38–0.58, p<0.001)
	Black	154 (17.6)	198 (13.4)	0.54 (0.42–0.69, p<0.001)	0.54 (0.41–0.71, p<0.001)
	Mixed	42 (4.8)	51 (3.4)	0.51 (0.33–0.78, p=0.002)	0.50 (0.31–0.80, p=0.004)
	Other	23 (2.6)	34 (2.3)	0.62 (0.36–1.08, p=0.083)	0.53 (0.29–0.99, p=0.043)
RPE mask model	Design A	63 (7.2)	307 (20.7)	–	–
	Design B	9 (1.0)	5 (0.3)	0.11 (0.03–0.34, p<0.001)	0.11 (0.03–0.35, p<0.001)
	Design C	159 (18.1	84 (5.7)	0.11 (0.07–0.16, p<0.001)	0.09 (0.06–0.14, p<0.001)
	Design D	38 (4.3)	33 (2.2)	0.18 (0.10–0.30, p<0.001)	0.16 (0.09–0.27, p<0.001)
	Design E	87 (9.9)	45 (3.0)	0.11 (0.07–0.17, p<0.001)	0.10 (0.06–0.16, p<0.001)
	Design F	47 (5.4)	43 (2.9)	0.19 (0.11–0.31, p<0.001)	0.18 (0.11–0.30, p<0.001)
	Design G	3 (0.3)	6 (0.4)	0.41 (0.11–1.98, p=0.216)	0.47 (0.12–2.33, p=0.305)
	Design H	2 (0.2)	7 (0.5)	0.72 (0.17–4.90, p=0.684)	0.64 (0.14–4.50, p=0.592)
	Design I	14 (1.6)	103 (7.0)	1.51 (0.83–2.91, p=0.193)	1.70 (0.93–3.31, p=0.096)
	Design J	214 (24.4)	233 (15.7)	0.22 (0.16–0.31, p<0.001)	0.24 (0.17–0.34, p<0.001)
	Design K	86 (9.8)	394 (26.6)	0.94 (0.66–1.34, p=0.735)	0.97 (0.67–1.39, p=0.863)
	Design L	152 (17.3)	218 (14.7)	0.29 (0.21–0.41, p<0.001)	0.29 (0.21–0.41, p<0.001)
	Others	3 (0.3)	4 (0.3)	0.27 (0.06–1.42, p=0.095)	0.29 (0.06–1.51, p=0.112)

D, disposable mask; R, reusable mask; RPE, respiratory protective equipment.

test attempts also did not materially change our findings (online supplemental figure B).

Male healthcare workers were significantly more likely to pass a fit test compared with females. Staff who describe their ethnicity as white were also more likely to achieve a successful fit test compared with staff who describe their ethnicity as Asian, black, mixed or other (table 3). There was wide variation in the likelihood of achieving successful mask fit between the different mask designs. The different mask designs were all N99 or FFP3 filtration, were CE marked and approved according to the European Norm EN149:2001 (online supplemental table). Mask designs demonstrated variable performance in terms of obtaining a successful fit (table 2). Investigating the conditional probability of successful fit at first attempt by gender and ethnicity, males were generally more likely to achieve success than females (p<0.001, table 3).

DISCUSSION

We investigated the suitability of respirators worn by healthcare workers and report new evidence that indicates lower RPE fit testing success rates among BAME and female healthcare workers.[3 4] This may indicate that certain groups may be at particular risk from COVID-19 infection in the workplace due to unsuitable respiratory protection.

The demographic diversity in our data may differ to the NHS England workforce. However, it is not dissimilar to the demographics expected of a healthcare facility

Table 3 Conditional probabilities of successful first attempt fit by gender and ethnicity

		Failed first fit attempt (n)	Passed first fit attempt (n)	Probability of passing first fit attempt (%)
Gender	Ethnicity			
F	White	206	163	44.2
	Asian	164	97	37.2
	Black	78	65	45.5
	Mixed	23	9	28.1
	Other	7	5	58.3
M	White	80	108	57.4
	Asian	66	56	45.9
	Black	15	17	53.1
	Mixed	3	4	57.1
	Other	9	7	43.8

Values are number or proportion.

in central London and so it is representative of London healthcare workers. BAME healthcare workers may account for 19.8% of the NHS workforce in England but ethnic minority healthcare workers demonstrate a higher representation in London (44.9%) with 1.7% identifying as having a mixed ethnic background.[14] Failure of RPE to protect BAME healthcare workers affects a significant proportion of the NHS workforce.

Our data suggest that there could be biases in design and certification of respirators. Respirator design has historically focused on the fit for individuals from the US Air Force in the 1967–1968.[10 15] However, it is unclear if the anthropometric data collected was even representative of the workforce in the 1960s and 70s as the US Air Force had clear height and weight restrictions and consisted mainly of men.[15]

Population demographics have changed drastically in the UK and US since the 1960s, with increased numbers of women and people from ethnic minorities in all workplaces. This historical data is therefore unlikely to reflect current workforce demographics.[6 14 15]

Recognising that the standard fit panels may no longer be appropriate, the National Institute for Occupational Safety and Health (NIOSH) conducted a new survey of the US work force in 2001.[16] A total of 4026 subjects from 41 different sites in, 8 states were recruited, and new fit moulding panels were proposed based on the anthropometric data collected.[16] However, the ethnic groups described in this study differ from the UK. The demographics of the workforce describes one-third of the population as Hispanic and specifically categorises the ethnicities as white, African American, Hispanic and other.[15 16] However, the largest ethnic group after White British in England and Wales is 'White other', followed by Asian-Indian, Asian-Pakistani, Black-African and Asian other.[12] Although NIOSH suggest their data can be used as a starting point for design and certification as the US population is ethnically diverse, the US data may not map accurately to the ethnic makeup of the UK healthcare workforce. Every individual has different features which vary by gender, ethnicity and even occupational role.[17] Face length is a key feature in respirator fit and this has been shown to vary significantly across ethnic and gender groups.[17] For example, anthropometric data show statistically significant differences in width and face and lip length between African-Americans and White Americans.[17] A sample of African Americans and Hispanic individuals in the US workforce were found to have up to face lengths 2.7 and 2.8 mm longer than white Americans.[17] Prior to COVID-19 most respirators were used in industrial applications such as construction. Construction workers are more likely to be male than healthcare staff, and have different facial features, including longer noses.[17] Gender has also been shown to be a major determinant in facial differences and measurements. Nine out of 10 facial measurements vary by gender with the female face being significantly smaller than the male face.[17] This is of relevance to respirator fit in healthcare workers as 77% of the NHS workforce is female.

Future respirator design should consider the facial characteristics of the demographic of the workforce. Face panels consisting of a true representation of female and BAME healthcare workers could help improve respirator design and improve safety when caring for COVID-19 patients. Out-dated fit panels used in the design and certification of the respirators demonstrate the institutional gender and racial biases in respirator fit and must be addressed in order to protect BAME and female staff.

Use of facial anthropometric data representing the current demographics of the workforce is not only important in the design of RPE, it can be used to guide procurement strategies for the ongoing pandemic. For example, females have on average smaller faces so looking at the different proportions of female vs male healthcare workers can guide what proportion of the procured respirators should be smaller versus large.

Examining the shape and measurements of the respirator in comparison to a face panel representing the workforce could help decision making in procurement. These techniques using facial anthropometric data representative of the workforce and observing the success or fail rate of different respirator designs in each ethnic or gender group could help with the decision-making process of which respirators to stock. Guiding procurement processes can prevent excesses of poorly sized respirators and shortages of the correct sizes.

However, even if the correct respirator for the demographic of the workforce was sourced, supply and demand issues of RPE early in the COVID-19 pandemic meant healthcare facilities could not rely on a steady supply of any single preferred respirator. Every respirator has a different design and fit, therefore individuals should be fit tested on the respirator model they don prior to patient interactions.[8 13] The multiple changes in respirator models mean healthcare workers must be repeatedly fit tested on the new models as supplies change. As healthcare facilities were overwhelmed with the need to fit test staff repeatedly on different masks many adopted an approach to fit check only.[9] Our data demonstrates that respirators have a variable success rate on initial fit test. For example, Design J did not suitably fit 24.4% of our staff. Some studies have demonstrated a fail rate as high as 78% when a respirator is used without fit testing.[10] Failure to fit test may leave a significant proportion of staff inadequately protected against COVID-19 and according to our data it is mixed ethnicity and Asian female healthcare workers who are at greatest risk.

Limitations

This was a single-centre study. The demographics of our data are representative of healthcare facilities in the London, however, further data should be collected to extrapolate the results to other areas. A large number of respirators were observed in this study and each individual did not test on every model. More data are required to evaluate the efficacy of each model. Finally, previous experience with fit testing was not accounted

for, although quantitative fit testing is objective and independent of experience, and the use of respirators was generally poor prior to the pandemic so we assumed a homogeneous lack of experience in our cohort.

Conclusion

Respirator design and certification may be biased towards fitting a demographic that is not reflective of the current healthcare workforce. This could leave many healthcare workers vulnerable as they struggle to fit into a mask not designed for their faces. Lack of design consideration and supply issues could be a dangerous combination for healthcare staff as they rely on the protection of a properly fitted respirator to reduce the risk of infection transmission while caring for patients with COVID-19.

Further research into the design and fit of RPE must consider the demographic of the healthcare workforce as we cannot rely on anthropometric data that represents only one section of the workforce. Creating new fit panels that accurately represent female workers and the ethnically diverse healthcare workforce is an essential first step towards designing well-fitting respirators. In the meantime, it is important to recognise that no one mask will fit all staff.[8–11 13] Therefore, the focus should be on employers stocking a suite of RPE, so that a diverse workforce has the best chance of finding a respirator of appropriate fit.

Ensuring fit testing and keeping adequate stock of a variety of respirator models can help maintain the safety of the whole workforce but future research should focus on the design of respirators for BAME and female healthcare workers.

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Data availability statement All data relevant to the study are included in the article or uploaded as online supplemental information. All relevant data are in the article. An queries will be answered if emailed to clarissa.carvalho@gstt.nhs.uk.

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