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REVIEW ARTICLE

The physical effects of wearing personal protective equipment: a scoping review

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Abstract

***Background*:** The COVID-19 pandemic has required healthcare workers to wear personal protective equipment (PPE), and although there is increasing awareness of the physical effects of wearing PPE, the literature has yet to be synthesised around this topic.

***Methods*:** A scoping review was conducted to synthesise existing literature on the physical effects of wearing PPE and identify gaps in the literature. A comprehensive search strategy was undertaken using five databases from 1995 to July 2020.

***Results*:** A total of 375 relevant articles were identified and screened. Twenty-three studies were included in this review. Studies were conducted across 10 countries, spanning 16 years from 2004 to 2020. Half (13/23) were randomised controlled trials or quasi-experimental studies, five surveys, two qualitative studies, two observational or case series and one Delphi study. Most (82%, 19/23) studies involved the N95 mask (either valved or unvalved). None specifically studied the filtering facepiece 3 mask. The main physical effects relate to skin irritation, pressure ulcers, fatigue, increased breathing resistance, increased carbon dioxide rebreathing, heat around the face, impaired communication and wearer reported discomfort. Few studies examined the impact of prolonged wear (akin to real life practice) on the physical effects, and different types of PPE had different effects.

***Conclusions*:** The physical effects of wearing PPE are not insignificant. Few studies examined the physiological impact of wearing respiratory protective devices for prolonged periods whilst conducting usual nursing activity. No ideal respirators for healthcare workers exist, and the development of more ergonomic designs of PPE is required.

Keywords: *healthcare workers; personal protective equipment; physical effects; physiological effects; review*

To access the supplementary material, please visit the article landing page

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The COVID-19 pandemic has brought the issue of wearing appropriate (to risk level), effective personal protective equipment (PPE) to the forefront for healthcare workers (healthcare professionals, HCPs). Important issues for staff at high risk (such as those in critical care units) are not only both the availability and correct fit of the PPE but also the physical impact of wearing PPE for prolonged periods when undertaking active clinical work. Previous systematic reviews have focused on adherence to wearing PPE by HCPs (1), the effectiveness of respirators and other measures in reducing the risk of infection in HCPs or others (2–4), comparing effectiveness between surgical masks and N95 masks in respiratory infection (5), but no paper has mapped the current evidence around the physical and physiological impacts of wearing PPE (for prolonged periods) on HCPs. The objective of this scoping review is, therefore, to map current evidence around the physical and physiological adverse effects and staff experience of wearing PPE for respiratory-transmitted infections. This will inform future decision-making and highlight gaps in the evidence base to inform future research.

Methods

This scoping review was undertaken using the five-stage scoping review method described by Arksey and O'Malley (6). Stage 1: identifying the research question; Stage 2: identifying relevant studies; Stage 3: study selection; Stage 4:

charting the data and Stage 5: collating, summarising and reporting the results. In this study, PPE was defined as wearing any component of respiratory protective devices (RPDs), eye protection, gown and gloves, for protection against respiratory-transmitted infections. This study has conformed to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) reporting checklist for scoping reviews (7) and is registered in OSF.HOME as a scoping review.

Stage 1: Identifying the research question

Our questions were developed in response to both a clinical and research need and are as follows: In HCPs (human participants) wearing PPE for respiratory-transmitted infections:

1. What are the physiological and physical effects?
2. What are the adverse effects of wearing PPE?
3. How do staff experience the physical effects of working in PPE?

Stage 2: Identifying relevant studies

We developed our search strategy in consultation with a medical information specialist (FB) who searched the following bibliographic electronic databases: MEDLINE, EMBASE, The Cochrane Library and CINAHL, using the Health Databases Advanced Search (HDAS) platform between 10 June and 8 July 2020 using the search terms listed in Table 1. We also searched the PROSPERO systematic review database and Google Scholar to capture any items not previously identified. We screened reference lists of included studies and relevant reviews. The search strategies for each database can be found in Supplementary File 1.

We included papers from 1995 onwards (25 years) to include other respiratory pandemics: severe acute respiratory syndrome (SARS) (2003), influenza A H1N1 (2009) and other influenzas, in addition to COVID-19. Only papers published in English were included, and we included both quantitative and qualitative research studies if the physical effects of wearing one or more components of PPE (defined previously) were studied or reported, if they were conducted in humans or HCPs or surveys where they examined HCPs perceived physical effects. Grey literature was searched, and any previously unidentified references were identified, but these are not included in the review. We excluded papers that examined HCPs ability to perform certain tasks (e.g. resuscitation) wearing PPE, those relating to adherence to PPE and contamination during donning and doffing, entirely laboratory or simulation based studies where the physical impact on humans was not studied, and studies specifically in pregnant women as this has been previously reported. This scoping review is also not looking at mask/PPE effectiveness, so papers examining this were excluded. General discussion papers, opinion pieces and non-English papers were also excluded.

Stage 3: Article selection

Stage 3 involved the clinical members of the study team (LT, DU, SC, CG and HP), screening all retrieved abstracts for potential inclusion, by applying the inclusion and exclusion criteria above. All abstracts were screened by two reviewers, and any discrepancies or ambiguity resolved by discussion with LT. If the relevance of a study was unclear from the abstract, then the full article was obtained (Fig. 1).

Stage 4: charting and extracting the data

The next stage involved data extraction and 'charting' key items of information obtained from the primary research studies. Data extraction templates were created: qualitative papers (key themes identified) and quantitative papers (numerical data extraction). Data were extracted into an evidence table (developed *a priori*), and this was checked for accuracy by the lead author (LT).

Stage 5: collating, summarising, and reporting the results

First, tables and chart mapping have been produced for the types of PPE studied, the physical effects and the time spent in PPE. Second, the literature has been organised thematically according to different physical effects reported with PPE.

Results

Three hundred and seventy-five research papers were identified through the searches (after duplicates removed) and screened. Six pieces of grey literature were located (these were national, professional society or company guidance and are not primary evidence included in the review), full text was obtained for 43 papers, and 23

Table 1. Search terms

Population	Exposure	Outcomes
Adult, humans and healthcare workers; healthcare professionals, nurses and doctors; occupational health; intensive care unit; phenomenology; experience	Personal protective equipment and respiratory protective devices; N95 masks; FFP3 masks; respirator; PAPRS and COVID-19; SARS, H1N1, influenza and pandemic; SARS-CoV-2	Physical effect, physiological effects, heart rate, carbon dioxide, skin breakdown, pressure ulcers, breathing, heat, exhaustion and fatigue; anxiety; confusion; tolerance; stress; reaction time; discomfort and nasal function

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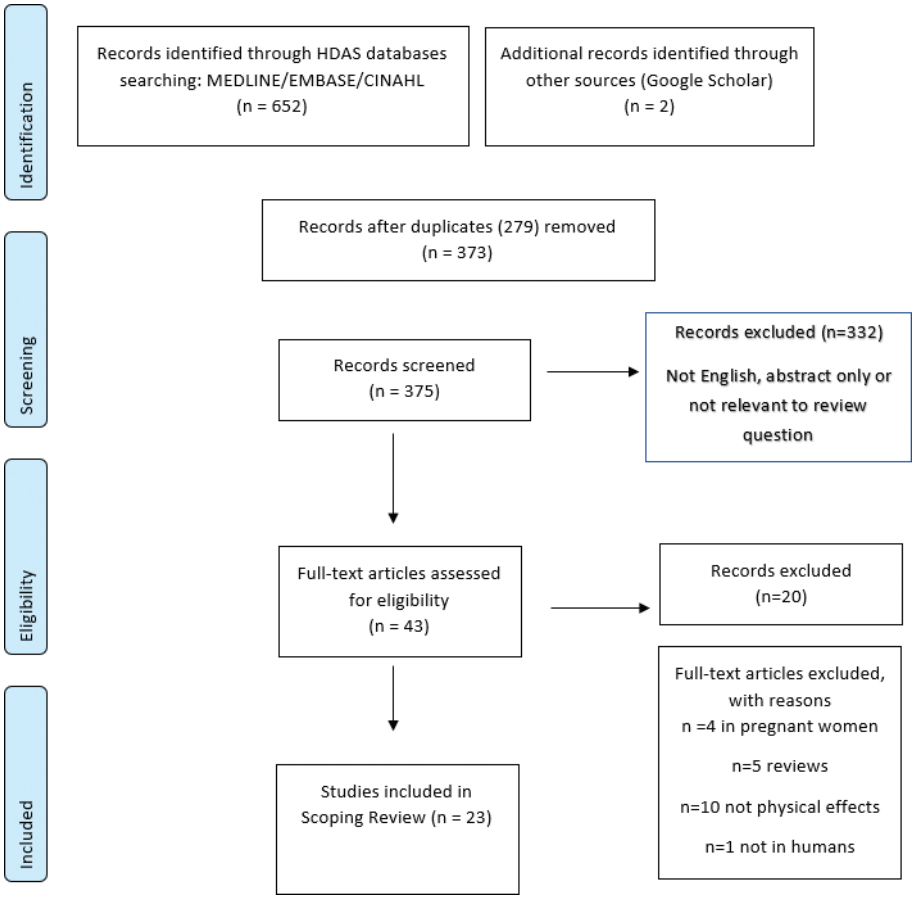

Fig. 1. The PRISMA diagram.

research papers met the inclusion criteria and are included in the review (Fig. 1). Studies were conducted across 10 countries, spanning 16 years from 2004 to 2020. Half (13/23) were randomised controlled trials or quasi-experimental studies, five surveys, two qualitative studies, two observational or case series and one Delphi study (Table 2).

Different types of PPE were studied (Fig. 2), most commonly RPDs, and of these, 82% (19/23) were N95 masks (either valved or unvalved).

Figures 3 and 4 summarise the main physical effects common to PPE. None of them specifically studied the model most used within Europe and the UK, the filtering facepiece (FFP) 3 mask, although other RPDs (like the N95) may produce similar effects.

The results of this review are categorised into six main themes:

- HCP reported physical effects of wearing PPE
- The respiratory effects wearing different masks/respirators
- Other effects of different mask/respirator
- The physical effects of wearing PPE on the skin
- Staff preferences of PPE type
- The impact of time and duration on the physical effects of wearing PPE

Healthcare professionals reported physical effects of wearing PPE

Eight of the studies (8–15) examined the reported physical effects of wearing PPE in HCPs: five survey designs including Delphi studies (9–11, 13, 15), one case series (8), one mixed method study (12) and one qualitative study (14). These studies were conducted in Singapore, Malaysia, the United States, China, Australia, Israel, Portugal and Iran from 2006 to 2020. Two of these focused specifically on skin effects, and these are discussed under that heading, with one study focusing specifically on headaches. Lim et al. (11) surveyed 212 HCPs about headaches when wearing the N95 mask. Thirty-seven percent reported headaches when wearing the N95, and over half of these (55%) had worn the mask continuously for >4 h. Staff who suffered from preexisting headaches suffered this symptom significantly more (P = 0.01). In a study (12) performed in Australia during the H1N1 pandemic, staff reported how difficult and uncomfortable wearing full PPE was and the impaired

Table 2. Summary of studies included in review (in order of level of evidence)

First author/year	Country/study design	Personal protective equipment (PPE) studied	Sample	Key findings
Randomised trials				
Loibner (2019)	Australia Randomised trial	PAPRS Suit A: TychemR F overall whole-body suit with a reusable light hood Versaflo S-655 and an external 3M Jupiter Powered Air Turbo Unit providing head-only positive pressure Suit B: 3M JS-series Type 3 Chemical and Respiratory Protective Suit with integrated respirator 3M Jupiter JP-ER-03 Powered Air Purifying Turbo fixed as a rucksack	10 male and 9 female volunteers aged 21–38 years. Wearing for up to 6 h at 22 degree and 4 h at 28 degrees with intermittent breaks form active tasks	3/19 subjects withdrew and did not finish the task. The most restrictive factors were reduced dexterity due to multiple glove layers, impaired visibility by flexible face shields and back pain related to the respirator of the fully ventilated suit. Heat stress and liquid loss were perceived as restrictive at a working temperature of 28°C but not 22°C. Discomfort due to sweat increased in both suits ($P < 0.001$) and significantly more with suit A than with suit B ($P = 0.003$)
Rebman (2013)	USA Randomised crossover trial	N95 respirator alone or with a surgical mask overlay	10 nurses working in a medical ICU aged 20–50 years, non-smokers, not pregnant	Most nurses (90%) tolerated wearing respiratory protection for two 12-h shifts Average time spent in N95 before removal was 214–199 min (day 1 vs. day 2) CO_2 levels increased significantly compared with baseline measures, especially when comparing an N95 with a surgical mask to only an N95 but changes not clinically relevant Perceived exertion; perceived shortness of breath; and complaints of headache, light-headedness and difficulty communicating increased over time. Almost one-quarter (22%) of respirator removals were due to reported discomfort
Quasi-experimental studies				
Shenal (2012)	USA Crossover trial	Medical mask (MM); duckbill N95 (DB); cup N95 (N95). Cup N95+ exhalation valve (N95+V). Cup N95+ medical mask (N95+MM). Cup N95+ exhalation valve + medical mask (N95+V+MM)	27 healthcare workers, aged 24–65 (mean 48 years [SD, 11 years], 15 women) Each served as own control and wore one of seven respirators ensembles or a medical mask for up to 8 h, or as long as tolerated	Average discomfort level was significantly different amongst respirators ($P = 0.0351$) and over time ($P < 0.0001$) The N95 had a significantly greater discomfort level than PAPR at 6 h (adjusted $P = 0.0065$) and at 8 h (adjusted $P = 0.0072$) Discomfort increased over time with continual respirator use over an 8-h period The level of self-perceived discomfort increased over time and across respirators. Facial heat pain and pressure are amongst the most common complaints associated with discomfort

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Table 2. (Continued)

First author/year	Country/study design	Personal protective equipment (PPE) studied	Sample	Key findings
Li (2005)	Hong Kong Quasi-experimental study	N95 (3M 8210) and surgical mask	10 healthy adults, 5 male and 5 female non-smokers	Significant differences were observed between N95 and surgical masks. Mean heart rate, microclimate temperature, humidity and skin temperature inside the facemask, together with perceived humidity, heat, breathing resistance in the facemask, itchiness, fatigue and overall discomfort were significantly ($P < 0.01$) higher for N95 masks than for surgical masks. The subjective perception of breathing difficulty and discomfort increased significantly with increasing thermal stress
Bansal 2009	USA Quasi-experimental study	HFM (unspecified) and N95 respirators	56 adults: 39 male and 17 females; mean age 47.5 years	Task affected tidal volume, minute ventilation, breathing frequency and heart rate; all were greater in heavier tasks The HFM led to prolongation of the inspiratory time ($P < 0.0001$), reduction of the expiratory time ($P = 0.0018$) and increase in the duty cycle ($P < 0.0001$) For most individuals, those that were healthy and with mild respiratory impairments, either respirator was adequate, although there was the potential for a small number of people to suffer more adverse physiological impacts
Roberge (2010)	USA Quasi-experimental study	2 N95 masks with and without an exhalation valve	10 healthy HCPs (7 women and 3 men, aged 20–45 years) who were experienced with wearing RPDs	The N95 with exhalation valve offered no benefit in physiological burden over the N95 without valve In healthy healthcare workers, N95 masks did not impose any important physiological burden during 1 h of use, at realistic clinical work rates, but the dead-space carbon dioxide and oxygen levels were significantly above and below, respectively, the ambient workplace standards, and elevated partial pressure of carbon dioxide (PCO_2) is a possibility An exhalation valve did not significantly ameliorate the masks PCO_2 impact
Lee (2011)	Singapore Quasi-experimental design	N95 (3M 8210) respirators (3M Korea Limited, Seoul, Korea)	14 healthy adults (7 males and 7 females) aged 18–25 years	Found a significant increase in breathing resistance, a mean increase of 126% and 122% in inspiratory and expiratory flow resistances, respectively, with the use of N95 respirators
Or (2018)	Hong Kong Quasi-experimental study	N95 respirators	84 nursing students (43 (51.20%) females and 41 (48.90%) males), with a weight range of 44.70–78.0 kg—all non-smokers	The participants were comfortable with the respirators at warm temperatures of 20–24°C For participants who had fit tests, they did neither feel hot nor had difficulties with breathing. However, they did feel tightness in the respirators and experienced discomfort on their ear lobes. Room temperature is the significant factor affecting the comfort in wearing N95 respirators

Table 2. (Continued)

First author/year	Country/study design	Personal protective equipment (PPE) studied	Sample	Key findings
Smith (2013)	Australia Quasi-experimental study	Full-face S.E.A. Pty Ltd Respirator with side-mounted filter	40 participants aged 19–58 (mean age 35); one female	Speech and work rates significantly increase CO_2 rebreathing in RPDs CO_2 concentrations in full-face RPDs may be linked to wearer discomfort and contribute to reduced tolerability and wear time of the device
Ozdemir (2020)	Turkey Qausi-experimental study	FFP2 respirator without exhalation valve (3M Aura™ 9320+, Minneapolis, US)	12 healthy male HCPs aged of 25–40 who were using PPE in the COVID-19 outbreak	EtCO2 values of the participants measured in all time periods by nasal route after wearing PPE were found to be statistically significantly higher than before wearing PPE (baseline) ($P < 0.003$) After 10th minute of wearing FFP2, all FiCO2 measurements were significantly higher than baseline FiCO2 value ($P < 0.005$) The use of FFP2 respirator *with a surgical mask cover* significantly increased the EtCO2 and FiCO2 values of healthcare workers
Zhu (2014)	Singapore Quasi-experimental study	N95 respirator and surgical mask	12 male adults and 65 female adults with age (21 and 60 years)	Baseline nasal resistance at baseline similar. At 1.5 h after mask removal, the mean nasal resistance reached the same level. The mean comfort level decreased with time, whilst wearing N95 respirator caused significantly more uncomfortable feelings compared to surgical facemask. The N95 respirator caused higher post-wearing nasal resistance than surgical facemask
Radonovich (2009)	USA Unblinded crossover study	Powered air-purifying respirator 3M, cup N95 exhalation valve, medical mask (no respirator) Precept duckbill N95 Kimberly-Clark; HFER North; Cup N95 exhalation valve medical mask; cup N95; cup N95 medical mask	27 volunteers (age, mean [SD]: 48 [11] years; range, 25–65 years), 15 women each participants randomly assigned a respirator ensemble to wear as long as they could 'tolerate' it whilst performing typical work duties	Tolerance time varied by respirator model. Women more significantly likely than men to experience intolerance before 8 h (hazard ratio, 1.97; 95% confidence interval, 1.02–3.75; $P = 0.04$). Participants discontinued wearing the respirator ensembles before 8 h in 126 of 215 total sessions (59%), reporting a variety of reasons for intolerance, including communication interference Wearing a cup shaped N95 without an exhalation valve was associated with more intolerance than a similar model with a valve
Observational studies				
Powell (2017)	USA Observational study	N95 FFP, one tight-fitting full facepiece PAPR, two loose-fitting PAPRs and one elastomeric/PAPR hybrid	12 adults (6 men and 6 women) aged 23 ± 3 years. Subjects wore each model for 1-h whilst treadmill walking at 5.6 km/h	Should state in a temperature 'controlled' environment during low-moderate work over 1 h, wearing a loose-fitting or tight-fitting PAPR does neither impact cardiopulmonary variables (SpO_2, transcutaneous partial pressure of CO_2 ($tcPCO_2$), pulse, respiratory rate) nor perceptions of breathing effort, breathing discomfort and ratings of perceived exertion differently than wearing an N95 FFR

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Table 2. (Continued)

First author/year	Country/study design	Personal protective equipment (PPE) studied	Sample	Key findings
Bulson (2019)	USA Observational study	Coverall suit, air purifying respirator helmet, x2 pair nitrile gloves apron and shoe covers	21 HCPs working in biocontainment unit	No statistical difference in pulse, blood pressure, SaO_2 or temperature between pre, during or post PPE use
Case series				
Lam (2020)	Malaysia Case series	N95 respirators (F550 CS)	5 HCPs working on ICU at a COVID-19 hospital (25–36 years) Prolonged use of N95 respirators > 5 h	Pressure ulcers over the dorsum of the nose following prolonged usage of the N95 respirator. Four cases were of grade 1, one a grade 3. On average, the N95 respirator was used over 5 h Fear of contracting COVID-19 led to HCPs securing masks too tightly
Survey designs				
Foo (2006)	Singapore Survey design	N95 respirators Gloves Gown	322 HCPs (276 women and 46 men aged 20–63 years), with a mix of races Worn for 6–8 h over a period of >8 months	Survey response rate 94.7% Masks: 109 (35.5%) of the 307 staff who used masks regularly reported adverse skin reactions, including acne (59.6%), facial itch (51.4%) and rash (35.8%) Gloves: 64 (21.4%) of the 299 staff who used gloves regularly reported adverse skin reactions, which included dry skin (73.4%), itch (56.3%), rash (37.5%) and wheals (6.3%) Gowns: only 4 (1.6%) of the 258 staff who wore gowns regularly reported adverse skin reactions
Hu (2020)	China Survey design	N95 mask Latex gloves Protective clothing	65 HCPs working with COVID-19 patients (20–59 years), with 5 men (8.2%) and 56 women (91.8%) (30 doctors and 31 nurses) Wearing a mix of PPE for long periods – up to 12 h day for an average of 3.5 months	**Adverse skin reactions of using N95 mask:** nasal bridge scar, 42 (68.9%); facial itching, 17 (27.9%); skin damage, 16 (26.2%); dry skin, 15 (24.6%); rash, 10 (16.4%); wheals, 7 (11.5%); indentation and ear pain, 7 (11.5%); skin desquamation, 6 (9.9%); acne, 1 (1.6%) **Adverse skin reactions of using latex gloves:** dry skin, 34 (55.8%); itching, 19 (31.2%); rash, 14 (23.0%); chapped skin, 13 (21.3%); wheals, 5 (8.2%); skin soaked with sweat, 3 (4.9%); oedema, 1 (1.6%) **Adverse skin reactions of using protective clothing:** dry skin, 22 (36.1%); itching, 21 (34.4%); rash, 7 (11.5%); wheals, 2 (3.3%)

Table 2. (Continued)

First author/year	Country/study design	Personal protective equipment (PPE) studied	Sample	Key findings
Hines (2009)	USA Survey design	N95s and EHFRs (like N95 but made of synthetic materials and contain filter-bearing cartridges), PAPRs	1,152 HCPs working in one of 5 sites within a single hospital	1,152 completed survey (no response rate) and 280 (24%) using EHFRs Regarding comfort, N95-FFR users rated their respirators significantly more favourably than did either EHFR ($P < 0.001$) or PAPR users ($P < 0.001$) Regarding communication, N95-FFR users again rated their respirators more favourably in comparison to EHFRs ($P < 0.001$) or PAPRs ($P < 0.001$) 1,152 completed the survey (no response rate cited) and 280 (24%) were currently using EHFRs For all user groups, reusable respirators were significantly more likely to be preferred over N95-FFRs PAPRs: communication and comfort ratings amongst PAPR users were lowest of the 3 respirators
Lim (2006)	Singapore Survey design	N95 respirators	212 HCPs: 47 male and 165 females; mean age 31 (range 21–58 years)	37.3% of those wearing N95 facemask had reported headaches when using, compared with 62% reporting no symptoms 55% of those reporting headaches had exceeded the recommended 4-h duration Continuous use of N95 mask ($P = 0.053$) was associated with headaches. 37% of those who had pre-existing headaches suffered more significantly ($P = 0.041$)
Parush (2020)	Israel and Portugal Survey design	A completely encapsulated suit and a self-contained breathing apparatus, such as the N95 face mask, which can provide full skin, eye and respiratory protection	722 HCPs in Israel and 301 from Portugal involved in the care of COVID-19 patients and using level 1 PPE; of the 524 (72%) males, participants include physicians (9%), nurses (6%) and paramedics (41%)	Responses showed high levels of difficulty for items related to discomfort, hearing and seeing, and doffing Difficulties in hearing, understanding speech and understanding the surroundings all rated highly Further analysis showed an association of PPE discomfort with situational awareness ($P < 0.01$), mediated by difficulties in hearing and understanding speech
Honarbakhsh (2017)	Iran Delphi study and the fuzzy analytical hierarchy process	N95 respirators	Phase 1: 284 HCPs with >2 years of experience Phase 2: 15 experts in the field of occupational health and safety	6 factors – including heat around the face, inaccessibility to respirators, difficulty breathing, pressure on the nose, trouble in communication, and no one does it – identified as the most important obstacles in using N95 respirators Of these, 4 factors – including heat around the face, inaccessibility to respirators, difficulty breathing and trouble in communication – achieved the highest score

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Table 2. (Continued)

First author/year	Country/study design	Personal protective equipment (PPE) studied	Sample	Key findings
Mixed method and qualitative studies				
Corley (2010)	Australia Mixed method study: survey then phenomenological study with interviews	N95 respirators	34 ICU HCPs: 28 nurses and 4 doctors	One theme rewearing of PPE: changing guidance around PPE created confusion, concerns the shortage of PPE, and the physical act of wearing PPE for an extended period was identified as a difficulty for staff Most staff were required to wear PPE for up to 12 h a day with only a 1–1.5 h break from PPE during this period. Many staff commented on how uncomfortable PPE was, especially for extended periods and difficulties in communication
Locatelli (2014)	USA Qualitative study with 3 focus groups	Staff who wore FFRs (non-type specific)	17 HCPs (94% female and 53% nurses) who worked in risk areas and who had worn FFRs as part of their work	3 themes found: experience of physical discomfort, physical features of the masks and the effects on patient care. Participants believed FFRs influenced patient care because patients felt uneasy and it changed health care workers' behaviours (loss of concentration, rushed patient care and avoidance of patients in isolation resulting from FFR discomfort)

PAPRs, Powered air purifying respirator; Co2, Carbon dioxide; MM, Medica Mask; HFM, Half Face Mask; FFP2, Filtering Face Protection (level 2); HCPs, Healthcare Professionals; EtCo2, End tidal carbon dioxide; FFR, Filtering Face Respirator; Sao2, Oxygen satisfaction; ICU, intensive care unit; EHRs, Elastomeric half mask respirators.

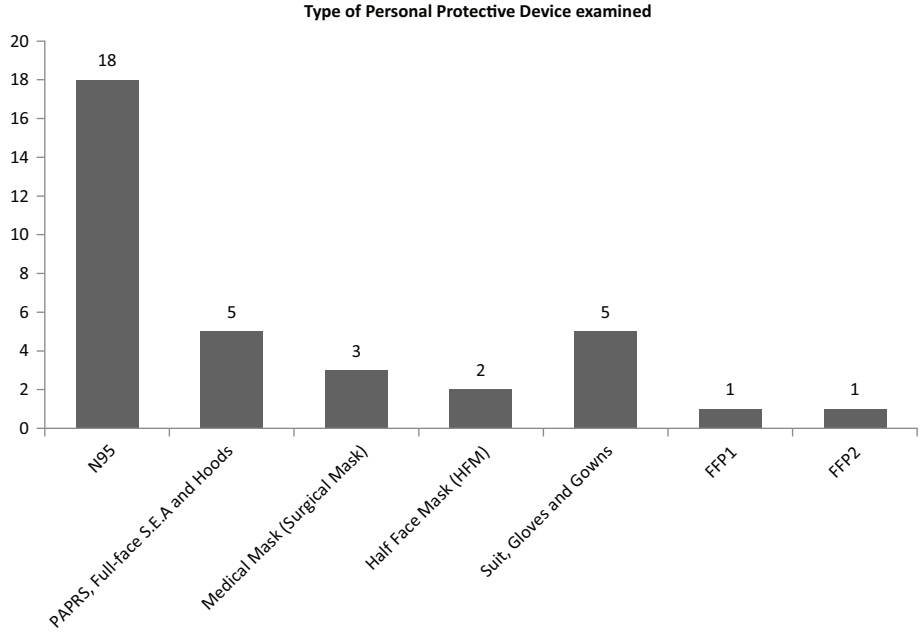

Fig. 2. Types of personal protective equipment examined in the number of studies. S.E.A. is a modified full face mask brand. Y axis represents the number of studies.

communication associated with it. A Delphi study (13) aimed to identify physical effects that acted as barriers to using the N95 mask in HCPs in Iran. They found six factors (four of these physical effects are as follows: heat around the face, difficulty breathing, pressure on the nose and trouble in communication) as the most important barriers for staff

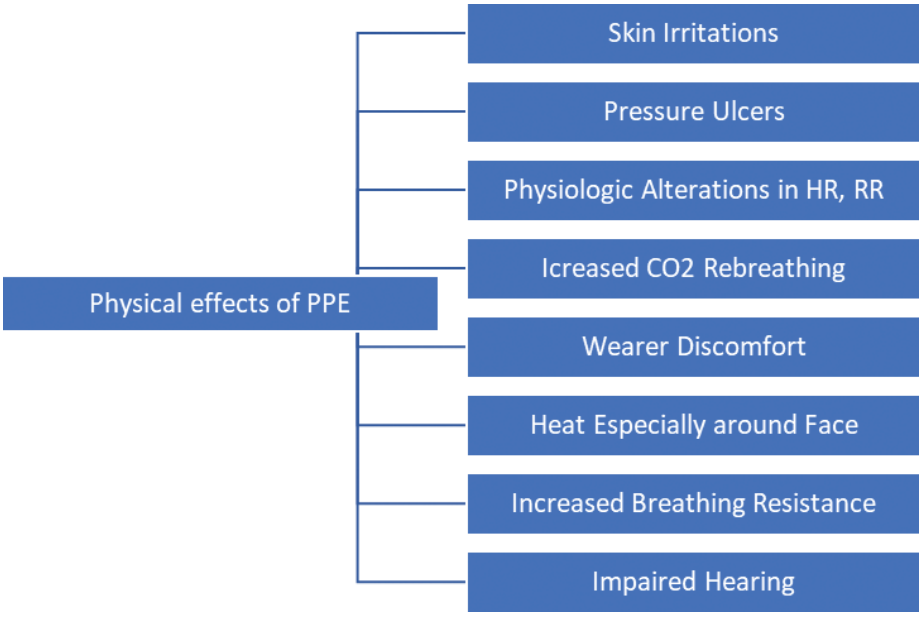

Fig. 3. Map of scoping review physical effects.

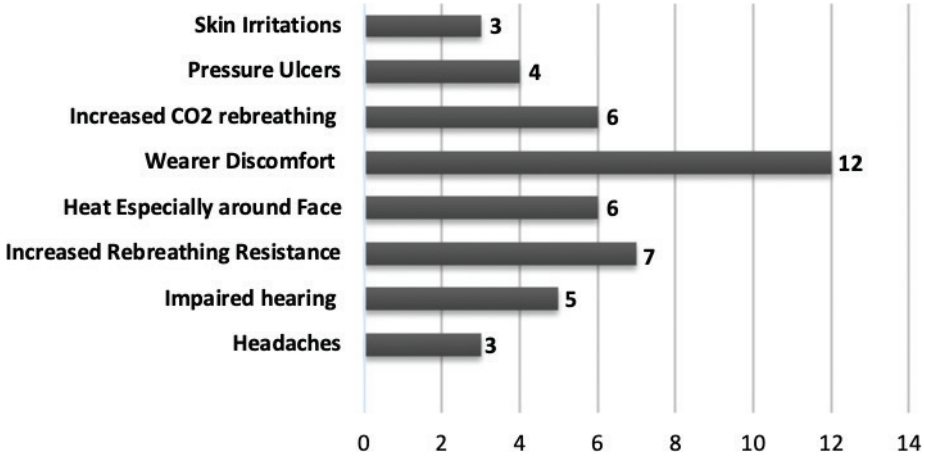

Fig. 4. The physical effects of personal protective equipment reported by study. X axis represents number of studies in which physical effects were cited.

using N95 respirators. Finally, a 10-item self-report survey (15) examined the key human factors: physical and ergonomic, perceptual and cognitive, which influence the use of level 1 PPE worn during the COVID-19 pandemic. In total, 722 HCPs in Israel and 301 from Portugal were surveyed (a mixture of males/females and nurses, physicians and allied health personnel). All respondents had worn level 1 PPE for at least a few hours daily to several hours weekly. They found high levels of perceived difficulty, with medians of 4/5 for items related to discomfort, hearing, and seeing and doffing. A subsequent analysis showed an association between PPE discomfort with impaired situational awareness ($P \leq 0.01$), with this association mediated by difficulties in hearing and understanding speech, reflecting difficulties in communication. Radonovich et al. (16) studied factors that resulted in mask intolerance by 27 HCPs. Heat and facial discomfort, impaired communication and other somatic effects (dizziness, nausea and itching) were the main factors contributing to this 'intolerance' of RPDs that necessitated removal of the device. They noted that women were significantly more likely to report intolerance than men.

The respiratory effects of wearing different masks/respirators

Twelve of 22 studies (13, 16–26) analysed the respiratory effects of wearing different respirators. These studies were conducted in Singapore (n = 2), Hong Kong (n = 1), the United States (n = 6), Australia (n = 1), Turkey (n = 1) and

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Iran (n = 1) from 2004 to 2020. The respiratory effects can be broadly divided in three themes: an increase in carbon dioxide (CO_2) rebreathing, an increase in breathing resistance and the effect on arterial oxygen saturations (SpO_2).

Smith et al. (17), in an exercise laboratory study, examined the physical consequences of speech and work rates and found that incremental CO_2 rebreathing occurs in RPDs. A quasi-experimental study (22) in healthy HCPs found that FFP respirators broadly did not have any significant physiological impact during 1 h of utilisation. However, the FFP respirator's dead-space, carbon dioxide and oxygen levels varied from the recommended working environmental standards, and elevated CO_2 levels were possible. In addition, the FFP's effect on CO_2 clearance was not enhanced by having an exhalation valve. In contrast, Randovich et al. (16) in a crossover trial of 27 HCPs found that wearing a N95 mask without an exhalation valve was associated with more intolerance than a similar model with a valve. Özdemir et al. (23) also examined end tidal CO_2 ($EtCO_2$) values of participants wearing PPE over time. They found that a statistically significant difference from that at baseline ($P < 0.003$) and after the 10th minute of wearing PPE CO_2 levels significantly exceeded baseline levels ($P = 0.005$). The use of an FFP2 respirator with a surgical mask cover considerably worsened the $EtCO_2$ and fractional concentration of inspired CO_2 ($FiCO_2$) values in participants. However, both Rebmann (24), in a randomised crossover trial of 10 nurses wearing N95 masks and Powell (25), in a prospective observational study of 12 adults, noted that although CO_2 levels were higher than at baseline, the changes were unlikely to be clinically significant.

The increase in breathing resistance is amongst the most important reported problems in HCPs wearing N95 respirators (13). Most of the studies report wearers perceived difficulty in breathing in RPDs, despite little evidence of any clinically significant physiological effects (24). Lee et al. (18) found a rise in nasal resistance after the removal of the N95 and surgical masks after 3 h of use, potentially due to nasal physiological changes. However, this study is limited by few (n = 14) participants and the inadequate duration of time monitored after mask removal to allow nasal resistance to return to baseline. Li et al. (19) in a quasi-experimental study of 10 participants found a substantial difference between the N95 and surgical masks, in addition to an alteration of the physiological parameters and wearer discomfort. Respiratory resistance was significantly ($P \leq 0.01$) higher in the N95 masks compared to the surgical mask, and subjective perception of breathing difficulty and discomfort also increased significantly with increasing thermal stress. Bansal et al. (20) compared the physiological impact of two RPDs in simulated work conditions (a dual cartridge half face mask respirator [HFM] and the N95 respirator) in 56 participants. They found that tidal volume, minute ventilation, breathing frequency and heart rate were all significantly higher in higher workload tasks. Despite this, they suggest that for most individuals, including those with mild respiratory distress, both types of RPD could be tolerated physiologically.

Three studies specifically examined the changes in SpO_2 in relation to the use of PPE. Two (21, 22) found no statistical difference observed between pre, during or post PPE use with regards to SpO_2, compared to the other physiologic parameters. They also found no significant differences between the type of RPD worn. Powell et al. (25) studied 12 healthy adults in a prospective observational study in a temperate environment during low–moderate work over 1 h, wearing a loose-fitting or tight-fitting powered air purifying respirator (PAPR). They found no impact on SpO_2 (or other physiologic parameters), or perceptions of breathing effort, respiration discomfort, associated ratings of perceived effort, other than that of wearing a N95 mask.

Other non-respiratory physical effects of wearing respirators or masks

Several other physical effects of wearing masks or RPD are apparent in these studies—the most common being facial heat, pain and pressure over the nose/ears, but headaches, light-headedness, pressure and skin irritations along with communication difficulties are also reported. Honarbakhsh et al. (13) in their Delphi survey of clinicians and infection control experts concluded that heat around the face and trouble in communication were the two top physical factors. Likewise, others (27) also noted facial heat, pain and pressure as other non-respiratory reported effects. Lam et al. (8) specifically studied headaches in HCPs wearing PPE and found these were worse in HCPs with existing headaches, and the likelihood of headache increased as time in PPE increased to near and beyond 4 h. Two studies specifically focused on skin irritation and pressure ulcers (8, 9), and these are discussed in the next theme. Importantly, in healthcare settings, communication difficulties both with hearing and speech are consistently reported in HCPs wearing PPE (12, 13, 15, 24). Parush et al. (15), in a large survey with over 1,000 responses across two countries, noted this and identified this impaired ability to communicate/understand significantly impaired situational awareness, which is critical for safety in a healthcare environment. Radonovich et al. (16) in an unblinded crossover trial of 27 HCPs found that heat and facial discomfort, impaired communication and other somatic effects (dizziness, nausea and itching) were the main factors contributing to 'intolerance' of RPDs that necessitated removal of the device. They noted women were significantly more likely to report intolerance than men, and wearing a N95 mask without an exhalation valve was associated with more intolerance than a similar model with a valve.

The physical effects of wearing PPE on the skin

Skin lesions and irritation were commonly reported in individuals wearing PPE. A case series (8) specifically reported pressure ulcers on the dorsum of the nose related to wearing an N95 mask in five HCPs, ranging from grade 1 to grade 3. In a survey of 322 HCPs in Singapore (9), other reported skin problems were acne (60%), facial itch (51%) and rashes (36%) whilst wearing the N95 mask. HCPs reporting acne were significantly younger than those who without. Prolonged wear of the N95 mask appeared to worsen the effect of these. A further survey of 65 HCPs in China (10) also found skin irritation, and in addition to those symptoms noted above, they found dry skin (26%), scarring of the nasal bridge (69%), wheals (11%), indentation and ear pain (11%) and desquamation (10%) associated with wearing the N95 mask. They also noted other skin effects related to the wearing of disposable gloves, with 64 (21.4%) of the 299 staff who used gloves regularly reporting adverse skin reactions, including dry skin (73.4%), itch (56.3%), rash (37.5%) and wheals (6.3%). Staff who reported dry skin and itching were younger compared with staff who did not. Hu et al. (10) also found staff reported skin issues related to wearing gloves: dry skin (55.8%), itching (31.2%), rashes (23.0%), chapped skin (21.3%), wheals (8.2%), skin soaked with sweat (4.9%) and edema (1.6%). Some of these effects are also inherently linked with frequent handwashing associated with managing infected patients. Few skin effects were associated with the wearing of disposable gowns. Two of the survey studies reported these: Foo et al. (9) found that only 1.6% of the staff who wore gowns regularly reported adverse skin reactions, whereas Hu et al. (10) found a higher rate of adverse skin reactions from using protective clothing: dry skin (22 of 65, 36.1%), itching (21, 34.4%), rashes (7, 11.5%) and wheals (2, 3.3%).

Staff preferences of PPE type

Undoubtedly, discomfort is the most reported physical effect perceived by HCPs wearing PPE. However, discomfort varies with the type of PPE worn and undoubtedly with the individual. This inevitably leads HCPs to prefer one type of PPE over another. Hines et al. (28) surveyed 2,252 HCPs on user acceptance of reusable respirators in health care (24% wearing elastomeric half-face respirator [EHFR], 53% wearing N95 respirators and 23% wearing PAPRs). In relation to perceived comfort, N95 users rated their respirators significantly more favourably than did either EHFR ($P < 0.001$) or PAPR users ($P < 0.001$). Regarding communication, N95 users again rated their respirators more favourably in comparison to EHFR ($P < 0.001$) or PAPR users ($P < 0.001$). Despite these preferences, when participants were asked about providing protection for them, EHFR users rated their respirators more favourably. Both EHFR ($P < 0.001$) and PAPR ($P = 0.012$) users rated their masks significantly more favourably than N95 users, based on their fit test. This contrasts with N95 users ($P = 0.003$), who would have needed a similar fit test, compared to PAPR users ($P = 0.005$), who still require training despite not having to undergo fit test.

The impact of time and duration on the physical effects of wearing PPE

Nineteen studies reported the duration of time participants were studied in PPE (8–12, 16, 27, 29, 30) (Fig. 5). The maximum time studied in PPE ranged from 5 to 720 min, and in the few studies, this ranged from 5 to 199 min, reporting the minimum time (20, 24, 25, 29). All studies that examined the physical effects over time found effects worsened with increasing time. Rebmann et al. (24) found that perceived exertion, shortness of breath, headache and light-headedness all increased over time with 22% of early PPE removals due to discomfort. Zhu et al. (26) also noted that mean comfort reduced as length of time wearing the N95 mask increased. Corley et al. (12) found staff (in practice) were expected to wear full PPE for 12 h shifts with a 1–1.5-h break (reflecting real life practice), and staff reported significant difficulties with this as time increased. Foo (9) and Shenal (27) also found staff perceived discomfort over time, with Shenal finding facial heat, pain and pressure the worse effects that increased over time (in an 8-h period). Loibner et al. (29) studied the effect of wearing two types of full PPE suits; both were uncomfortable for staff, and the effects of this discomfort worsened as the time in the suit increased. Radonovich (16) found that 59% of HCPs discontinued wearing the respirator ensembles before 8 h reporting a variety of reasons for this intolerance, including communication interference, along with physical effects.

Discussion

We used a systematic methodology and searched a range of databases to capture the full range of existing studies on the physical effects of PPE in HCPs. This review has achieved the study objectives. First, this scoping review has identified the most common physical and physiological effects and adverse effects of wearing PPE. These effects (summarised in Fig. 3) are most commonly respiratory effects, pressure ulcers, other skin irritations, heat, impaired communication and general wearer discomfort. Staff experience wearing PPE is generally negative, although use is recognised as essential. Impaired communication and wearer discomfort, which worsen over time, have been shown.

This review highlights the gaps in research, especially specifically around the FFP 3 mask (used most within the United Kingdom), and the differences between this and other RPD types such as the N95 and FFP2. Furthermore,

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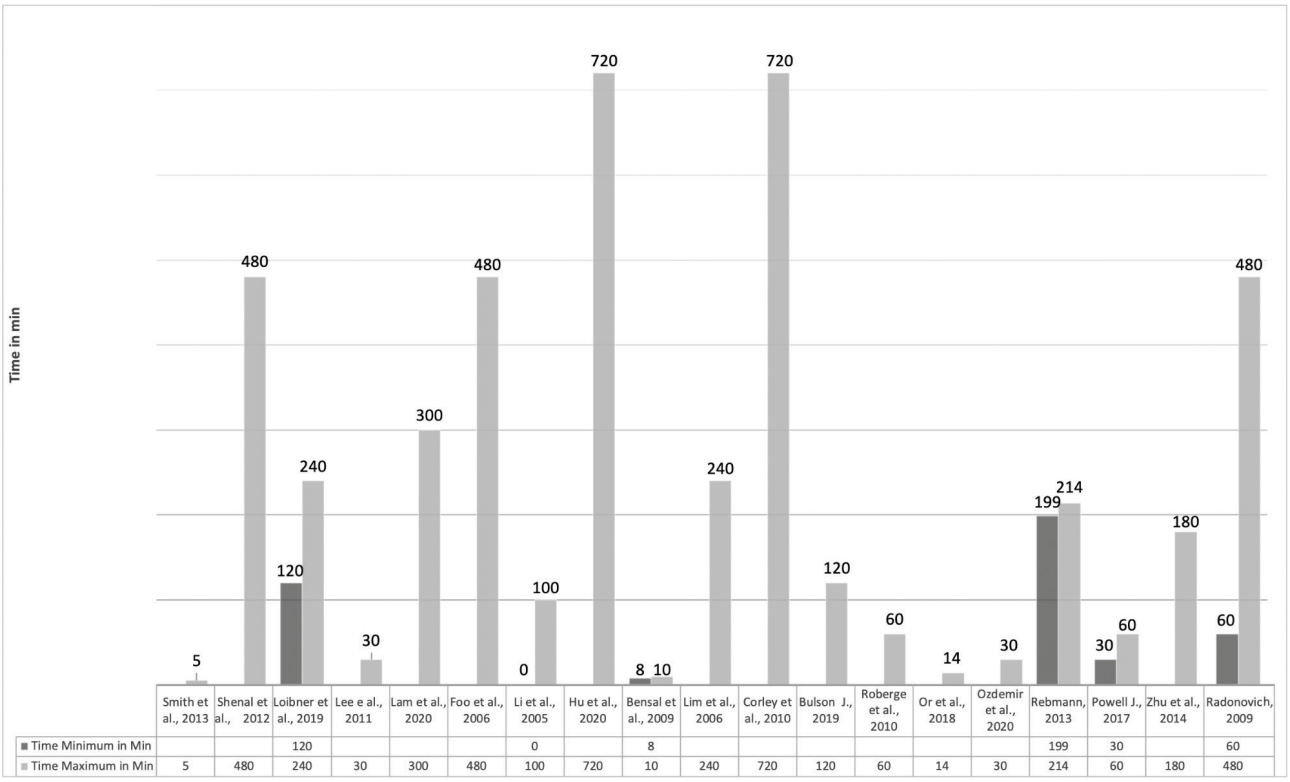

Fig. 5. Time spent in PPE as reported by study.

as RPDs vary in design and level of protection, one RPD type will not provide the same level of comfort to all HCPs. Historically, PPE and RPDs were designed for men in industrial situations (31), yet many healthcare workers (especially nurses) are female and from multiple ethnic backgrounds in the United Kingdom; this has implications for the 'fit' and comfort of RPDs, and this has not been adequately researched. Future studies need to explore this. Improving the acceptability and usability of wearing PPE for HCPs, including ease of communication and physical comfort, was identified as a research priority in 2010 by a large US report funded by the US Institute of Medicine, yet this remains a significant gap in research (32).

Currently no 'ideal' RPDs for HCPs exist, and we know that a 'one size fits all' approach does not work (33). More research is urgently required to develop a more individualised approach to RPD fitting and wearing, to maximise comfort for staff. Some of the studies compared both valved and non-valved RPDs, not showing any significant different in respiratory effects. Valved RPDs are designed to make expiration easier, and thus more comfortable to wear, with less moisture build up inside the mask (34). The downside to this is the failure to filter the wearers exhalation, providing only one-way protection (for the wearer) and potentially placing others at risk (34). During COVID-19, with reported widescale asymptomatic infections (some of these amongst HCPs) and many patients in hospital settings, especially in intensive care units, not required or able to wear masks, this potentially puts them at risk (35).

Gaps in the literature

There are clear gaps in the evidence identified from this scoping review. No UK studies exist, and no studies have specifically examined the impact of FFP3 masks (worn extensively in the UK and Europe); although likely to be similar to the N95, this is not known. Furthermore, there is limited evidence on the physiological impact of wearing PPE (in particular RPDs) for more than 2 h whilst conducting moderate nursing tasks in standard hospital temperatures, recommended to be 18°C (36), and comparing different ethnic groups with different physical facial features.

Limitations

There are several limitations to this scoping review, although it was based on a comprehensive review of the literature, with expertise from an information specialist. It is possible that some relevant studies were missed, as we only included studies published in English. We also excluded studies that specifically examined HCPs' ability to perform, non-human laboratory or simulation-based studies, and those studies specifically of pregnant women

as this has been previously reported (37). A further limitation of our methods is that papers are not critically appraised in depth and the evidence level graded; however, what we have done is map the literature on this topic and identified gaps for further research as well as the clinical implications.

Clinical implications of the scoping review

The physical effects of wearing PPE (even RPDs alone) are not insignificant, and these effects are magnified over time and in warmer environments. Managers must be highly cognisant of these effects and ensure HCPs have adequate frequent breaks from PPE and, where possible, the environmental temperature modified to improve comfort. This requires both a review of staffing and working practices to facilitate. Adequate occupational health input is also important to prevent, reduce (where possible) or treat these physical effects in HCPs. History suggests that this pandemic will not be the last, thus further research and development of newer more ergonomic PPE is essential.

Conclusions

Currently, no 'ideal' PPE exists for HCPs, with numerous physical effects reported and quantified. Working effectively in PPE continues to be challenging, since it is necessary for clinical staff to wear PPE for prolonged periods. Having knowledge of these physical effects directs future designers of PPE to develop more ergonomic designs and researchers to gaps in our knowledge, especially around the impact of FFP3 masks worn in the United Kingdom. This knowledge also directs managers to reconsider the work pattern and staffing levels required for staff working in PPE to ensure more frequent breaks can be undertaken to ensure both worker safety and effective and safe care delivery.

Conflict of interest and funding

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Ethical considerations

Ethics approval was not required for this study.

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