

# Surveying Healthcare Workers to Improve the Design, Wearer Experience and Sustainability of PPE Isolation Gowns

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*This protective clothing design project responds to the urgent need for research into the redesign of personal protective equipment (PPE) isolation gowns, to be more fit for purpose and reusable to enhance the experiences of healthcare workers treating patients with COVID-19 and variants. Funded by the Arts and Humanities Research Council (AHRC) the research addresses the engineering question: “What new materials, design and manufacturing approaches should we start to consider in preparation for pandemics e.g. reusable PPE to replace single use?” The article focuses on the online questionnaire/ survey, its main findings and the ‘participatory clothing design’ methodology which prioritises the lived experiences and expressed needs of healthcare workers wearing disposable and reusable PPE in acute care scenarios. Research methods include literature and gown reviews, selected interviews and survey directed at nurses, to acquire first-hand qualitative data about the impact of current gown design and procurement policies on wearers. Selected results and commentary from the ongoing survey are presented and thematically analysed to inform the development of reusable gowns. Semi-structured interviews with clinical leads and caregivers, as well as responses from users, will be important to integrate expertise in fashion, textile and uniform design, clinical practice, and manufacturing. Further design will be based on a complex design brief that balances the needs of wearers and critical care providers while considering regulations, protection, comfort, sustainability, and cost. This research focuses on enhancing an overlooked area of critical care clothing and the people who wear it while reducing its detrimental impact on the planet.*

**Keywords:** healthcare workers, survey, isolation gown, reusable PPE, wearer experience, qualitative research

## Highlights

- Gown review involving the contextual and sensory analysis of disposable and reusable gowns, including items supplied by the NHS and industry partners.
- Qualitative analysis of interviews and survey responses to identify key gown design issues.
- The literature review, interviews, market research and survey feedback, represent a creative, collaborative, and complementary way to define the foundation for further redesigning PPE.
- The goal we pursued was to identify critical key elements that could improve the user experience with PPE.
- Reusable gowns are more sustainable solution than disposable gowns.
- The critical situation shows the one-size gowns that hindered the work of all users who were at least 160 cm tall, which was 35 % of our respondents

## 0 INTRODUCTION

The research was undertaken for the project: ‘Redesigning PPE: enhancing the comfort and safety of healthcare workers wearing isolation gowns to treat patients with COVID-19’ [1]. The project was devised to tackle the engineering-based question: “What new materials, design and manufacturing approaches should we start to consider in preparation for pandemics e.g. reusable PPE to replace single use?” [2].

Following a review of recent literature, reinforced by findings from our online survey, we identified particular dissatisfaction with the performance of disposable oversized gowns. This was acknowledged early in the pandemic by the Royal College of Nursing [3] who recognised that a generic “one-size-fits-all” (one-size) approach to personal protective equipment

(PPE) was “problematic” and “restrictive” when worn for 12-hour shifts [4].

Our research goal was to find the best possible solution to a crisis in which the PPE industry was adopting a non-circular, single-use approach to meet demand, resulting in human and environmental problems. Through contact with leads in Clinical Procurement and Therapies from Northampton, and Nottingham University NHS Hospital Trusts in the East Midlands, UK, we obtained initial information about their nursing teams’ experiences of wearing disposable gowns. Based on this collaboration and a review of products on the market, we prepared a survey for different health professionals to complete anonymously. Their responses revealed the most common problems with wearing generic gowns. Based on the analysis of the interviews, we applied ‘material methods’ [5] to design models by researching details, developing sketches, patterns and specifications

resulting in prototypes incorporating variations of sizing, cuffs, necklines, and fastenings.

The goal of the article is to highlight the relationship between problems observed in practice, the importance of research, and the involvement of users with practical experience, whose information is crucial for developing clothing that supports people's working needs.

## 1 METHODS

This practice-oriented study responds to the identified need for research into PPE isolation gowns. The first step was the literature review. We analyzed journal articles, press and reports. The product review of disposable and reusable isolation gowns included measurements, specifications, design details, construction techniques and fabrication.

After researching papers to gain insights into the problem, we then interviewed Clinical Procurement and Therapist managers in NHS Trusts. We had five discussions with project partners in the (Northampton General Hospital (1), Queens Medical Centre (1) and Nottingham University Hospital Trust (1), Diaverum (2)) and five online interviews with medical staff from different healthcare organisations.

Based on this information, we prepared a related survey that we sent to healthcare professionals in the East Midlands, UK. The individual responses to survey questions, predominantly from nursing staff working in acute care provided qualitative data which was 'thematically analysed' [6]. Creative methods of experimental research included textile sourcing, gown design and garment detail developments. The findings informed the subsequent phases of design development. This 'constructive design' approach prioritises knowledge of the 'action of the body' of the healthcare wearer (HCW) alongside theoretical and practical methods [7].

The co-design methodology draws on the principles of 'participatory clothing design' by involving and acting on the lived experience of the wearer [8] though the application of an 'intentional, circular' approach that considers PPE product lifetime [9].

## 2 EXPERIMENTATION

The research group members met weekly on the MS Teams platform to exchange research ideas, references and emerging findings. This hybrid way of working, online and in real time resulted in an experimental 'visual methodology' [10] comprising text, gown

dimensions, contextual images and photographs. Visual research information was developed and disseminated using Conceptboard [11].

The literature review, interviews, market research and survey feedback, represent a creative, collaborative, and complementary foundation for redesigning PPE. The goal we pursued was to identify critical elements that could improve the user experience of PPE gowns.

The methods are presented in the following subsections.

### 2.1 Literature and Gown Review and Interviews with Clinical/ Procurement Leads

The first phase of the research was carried out between February and April 2021 (10 weeks) to fulfil Aim 1: Understand the issues experienced by health workers wearing PPE gowns. Gowns are primary garments classified as uniforms intended for employees of various professions in the public sector, as corporate clothing, for tourist or sports purposes. In all examples, in addition to clothing for protection at work, uniforms are also clothing that provides information about what we can expect from the person we meet in certain clothing [12].

Common to all uniforms are the special properties of fabrics that can provide durability in different workplaces and working conditions. All uniforms are also an important tool of communication in society, but in the case of uniforms for healthcare workers, a focus on practical solutions has resulted in an overlooked area of design with potential for improvement.

The design of uniforms must be, above all, functional and supportive to facilitate the roles of healthcare workers. Our literature review identified various examples where isolation gowns failed to adequately support staff in their work in relation to design [13], inappropriate size or length [4], or unsuitable, heat-inducing fabrication [14]. Direct user feedback is therefore very important for designers and manufacturing companies to be able to constantly improve the design of critical clothing items [15].

The methodology merges principles of interpretative phenomenological analysis and co-design to acquire empirical evidence to act upon, comprising qualitative data of the 'everyday phenomenon' of wearing of an isolation gown and quantitative data in the form of gown measurements, specifications, and textile composition [8]. Analysis of both sets of data provided a platform for adopting an intentional design approach with the aim of developing a circular gown system which can sustain

the end user more effectively through an extended product lifetime [9].

Medical gowns play an important role in protecting the health care from the transmission of microorganisms and body fluids. [16]. The decision of whether a hospital uses a reusable or disposable gown is a selection process based on factors such as sustainability, barrier effectiveness, cost, and comfort [16]. The results of a US-based study into environmental implications of disposable vs reusable showed that compared to the disposable gown system, the healthcare facility had “a 28 % reduction in energy consumption, a 30 % reduction in greenhouse gas emissions, a 41 % reduction in blue water consumption, and a 93 % reduction in solid waste generation.”[16]. The researchers conclude that choosing reusable gowns over disposable gowns can have significant environmental benefits. The US-based Centers for Disease Control and Prevention (CDC) also recommend that in situations such as the current COVID-19 pandemic, washable isolation gowns should be used [17].

The gown review involved the contextual and sensory analysis of 30 disposable and reusable gowns, including 12 physical items which were ordered online, and two garments supplied by the NHS and the industry partner. An overview of the rationale and process of analysis is provided in a short video [18].

All (12) gown models were also measured and compared. We particularly focused on the gown length (front and back); neck, shoulder, sleeve, and cuff (width and length); chest, waist, hip circumferences. Table 1 illustrates the variations in sizes between five disposable and two reusable gowns.

All the models were reviewed by three members of the research team who are respectively a UK dress size 10, 12 and 14. When trying the gowns on, the researchers adopted various body positions, mimicking those involved in treating patients e.g. bending (as if over a bed), reaching forward (Fig. 1) walking quickly etc. Best fitting disposable and reusable gowns can be basis for paper patterns. An

average of these measurements informed the design and dimensions for the first prototype.



**Fig. 1.** Reviewing the same disposable model on two different sized people (UK 10 and 14) in various postures

Up to 10 semi-structured interviews are planned to be undertaken with clinical leads and nursing staff throughout the project. In April 2021 we interviewed the Clinic Manager at Diaverum, UK, Nottingham (online) where he revealed that the organization procured disposable gowns in one-size for all staff, which were incinerated after single use. The gowns are used to protect staff when treating patients

**Table 1.** Measurements of different gowns [cm]

Model Nr.	Length front / Length back	Neck width / Shoulder / Sleeves / Cuff	Chest, Waist & Hip circumference / Size
1. Arma (Disposable)	106 / 112	26 / 20 / 55 / 4.5	69 L (one-size)
2. Bestsanitizer (Disposable)	113 / 110	19.5 / 24 / 54 / 5	71 (one-size)
3. SubMed (Disposable)	119 / 112.5	22.5 / 19 / 59 / 7	71 (one-size)
4. Lux (Disposable)	129 / 116	N/A / 81 / Thomb hole	90 (Unisex)
5. Matrix (Reusable)	128 / 125.5	24.5 / 22.5 / 55.5 / 10	133 (L)
6. Sciquip (Disposable)	118.5 / 111.5	22.5 / 80.5 / Thomb hole	108 (One-size)
7. Swallowdental (Reusable)	115 / 121	18 / 24 / 57 / 10 /	139 (One-size)

with different kidney related diseases, hepatitis B, Cytomegalovirus (CRV) and coronavirus. He pointed out that while most nurses found the gowns comfortable, they were too large and long for shorter and petite builds. This included male members of the nursing team, reinforcing the fact that this was a non-gendered general issue, despite impacting more of the 75 % of female nurses in the NHS [4]. The disposable gown donated to the team by Diaverum, included a ribbed neckline, which was very comfortable to wear, while providing a good fit and better protection for the skin.

In addition to the sizing issue, a common problem raised by his staff was the heating effect of the composite polyester fabric. This issue is often exacerbated by waterproof PU (plastic) coatings on both disposable and reusable gowns causing the wearer to experience 'heat stress' [14]. Similar issues were identified in other interviews with a head of theatres, an Intensive Care Unit (ICU) nurse, a trainee doctor and an anaesthetist from different NHS trusts.

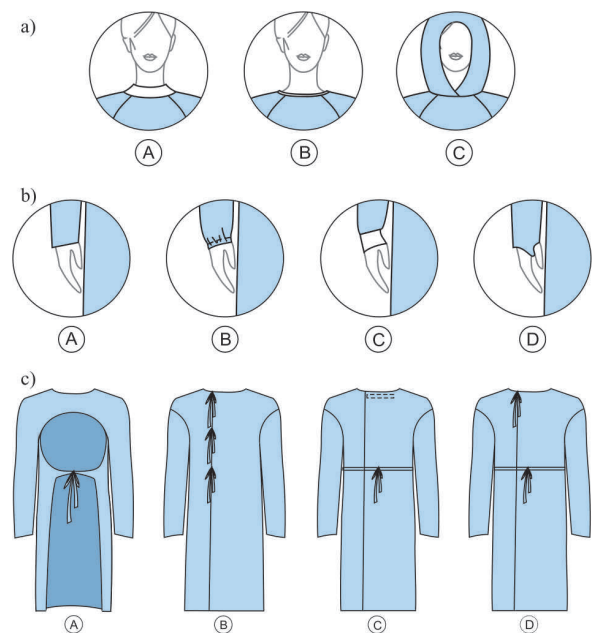
## 2.2 Survey

The survey was designed in response to the initial findings of the literature, gown reviews and interviews [18]. We developed 25 questions to address key criteria for redesigning PPE isolation gowns, with emphasis on enhancing the comfort and safety of healthcare workers treating patients with COVID-19. Initially, the survey was sent to our two main NHS partners in Nottingham in July 2021. Due to the low response rate impacted by the ongoing pandemic, the survey remains open and has been extended to nurses outside of Nottingham. At the time of writing this article there were 123 respondents.

The survey asks several different types of questions. General questions (about age, gender, ethnic background, their own assessment of a disability, where they work and which area of the hospital/healthcare organization they work in and their position), what type of gown they wear and what they wear underneath. We enquired about the textile composition, details the size they normally wear.

As far as possible the answers to the questions were prepared in multiple-choice illustrated groups (Fig. 2) to make the process expedient, but with space for descriptive answers. We also incorporated the possibility of choosing between contrasting positive/negative responses to specific aspects of the gown (e.g. feelings of comfort and safety) with 5 possible marks; Number 1 referring to the first parameter (very comfortable) and Number 5 the opposite parameter

(uncomfortable), with the choice of three marks in between, the middle score (3) denoting a neutral response. In this article we focus mainly on the percentages accrued for 1, 2 and 4, 5, and disregard 3.



**Fig. 2.** Examples of the illustrated multiple-choice approach to questions about a) necklines; b) cuffs and c) waist fastenings. [20]

### 2.2.1 General Survey Questions and Answers

In common with many surveys, the first two general questions cover information about the age and gender of the respondents. The highest percentage (36.4 %) were between 25 years and 34 years and between 35 years and 44 years old (28.9 %) with 19 % between 45 years and 54 years old. Fewer than 10 % were aged 55 to 64 and the smallest number (4.1%) between 18 and 24. A ratio of 81.8 % females and 17.4 % males replied. This latter statistic is in keeping with press articles about poor PPE performance and generic sizing, putting females who make up 75 % of health staff at greater risk than males [4].

In terms of ethnicity, 76.9 % of the respondents were white, 7.4 % from other Asian backgrounds; 4.1 %, black or black British-African and the same percentage Asian or Asian British-Indian, with 1 % identifying as being from different mixed ethnicity backgrounds. These figures are not representative of the NHS workforce which is much more ethnically diverse than these percentages suggest (Ref) and an important consideration for future PPE design and PPE procurement policy. 4.1 % considered themselves to have a disability, and 1.7 % preferred not to say.

Initially, the majority of the survey participants worked for our project partners, Nottingham University Hospital Trust (NUHT) and Diaverum, UK. However, following publicity about the project in late November 2021 we received replies from nurses working across the UK, including in Scotland, England, Wales and Northern Ireland.

Nearly 81.5 % of all respondents worked in ‘high-risk environments’ and defined themselves as working with covid patients in various nursing roles including in: dialysis, critical care, mental health, intensive care, theatres and recovery, as healthcare assistants, clinic managers, in a Hot Zone in an Emergency Department and Intensive Care Unit (ICU) involving respiratory and aerosol generating procedures (AGP).

In the following sections we analyse the survey responses in relation to the themes of ‘wearability, comfort, fit and sustainability’.

### 2.2.2 Disposable and Reusable Gowns, Donning and Doffing

The majority of surveyed respondents, 75 % confirmed they wear disposable gowns and 25 % reusable gowns 25 % (Fig. 3). In terms of duration, 26.5 % generally wearing these protective garments for 8 h to 12 h, 23.6 % wear them for between 1 h and 2 h or 3 h and 4 h, and 13 % for 4 h to 8 h. 12.2 % of the respondents highlighted ‘other’ timescales (Fig. 4) supported by comments about wearing multiple, single-use PPE during shifts, depending on the medical treatment: “New gown with each patient or entry to a room - sometimes for as short a time a few minutes sometimes for 1 h to 2 h.”

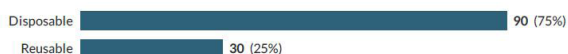


Fig. 3. Survey answers to Question 7: Are the gowns you wear disposable or reusable?

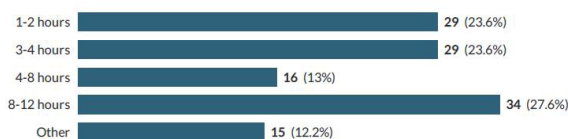


Fig. 4. Survey answers to Question 8: How many hours do you generally wear your isolation gown for?

In response to Question 9: What do you wear under your gown? the healthcare workers generally cited scrubs (80.2 %), undergarments (3.3 %), or 18.2 % non-uniform clothing such as a tunic and trousers, skirt and top or dress.

Question 10: Is your gown easy to put on (don) and take off (doff)? The respondents had very different experiences, depending on the type and fabrication of the gown they wear (e.g. disposable/polyurethane), how experienced they are, and how much time they have to put it on or take it off. Some reported ‘no problems’ while others suggested that ‘proper training is required.’

With reference to donning, we discussed two parameters: Easy to put on (score 1) vs. difficult to put on (score 5). Some respondents said they needed help to cross the back and/or fasten the ties. Those with experience of wearing hooded gowns or hazard suits experienced greater difficulty in getting dressed. Similarly, with undressing or doffing: Easy to take off (score 1) vs. Difficult to take off (score 5), The answers demonstrated that 47.1 % of the respondents can easily remove their gowns (score 1) and 20.7 % (score 2). A total of 19.8 % of the respondents chose score 3 and only a minority of the respondents confirmed difficulties in doffing taking off the gowns, namely 9.9 % (score 4) 2.3 % scoring 5.

This result was unsurprising, as most respondents wearing disposable gowns, just pull or rip them off at the end of use because the paper-like composite fabric tears quite easily, although, the velcro fastenings can pull on the neck, as reiterated: ‘Sometimes the gowns tear whilst donning using closed glove method. Sometimes the ties disconnect whilst donning and sometimes they are difficult to undo or pull apart to remove.’ Some nurses also need help removing gowns carefully to avoid cross-contamination.

### 2.2.3 Impact of Fabrication on Wearer Experience

In our gown review we found that most disposable gowns were fabricated in non-woven spunbonded polypropylene. The reusable gowns were fabricated in PU (polyurethane/plastic) coated polyester. With the exception of one polythene and one traditional surgeon’s gown in polyester/cotton, all these PPE products met EN 13795-1 [19] safety standards required for surgical gowns or drapes.

To undertake in-depth analysis of the gown’s fabrication and its impact on the wearer, we subdivided some of the questions to gain insights into the positive and negative aspects of the materials as ‘active participants’ in the study [5].

We discussed many parameters: fit (good (score 1) vs poor (score 5), feel (cool (1) vs warm (5), textile quality (good (1) vs poor (5), manufacturing quality (good (1) vs poor (5), fastenings practicality (practical (1) vs impractical (5), lightness of material (light

(1) vs heavy (5), softness (soft (1) vs stiff (5), water repellency (waterproof (1) vs absorbency (5) and breathability (breathable (1) vs non-breathable (5).

Regarding the fit of the gowns, 19.3 % of healthcare workers agree that the gowns are good fit with a score of 1, 14.3 % chose a score of 2, 29.4 % a neutral rating of 3. Another 16 % gave a rating of 4 and 21 % gave a rating of 5. If we add the first and last two scores, this equates to 33.6 % being comfortable and 37 % being uncomfortable, which is over one third of the workforce.

For feeling cool vs warm, many more respondents confirmed that the gowns are too warm, causing discomfort [14]. As illustrated in Fig. 5, only 14.5 % (scores 1 and 2) found their garments cool, while 76.1 % (scores 4 and 5) suggested that their gowns were heat inducing, with 54.7 % scoring 5, evidencing the seriousness of this issue (Fig. 5).



**Fig. 5.** Survey answers to Question 11.2: What are the positive/negative aspects about wearing the gown: cool vs warm?

In Question 11.3: Good vs poor textile quality, the prevailing opinion was negative, with 9.2 % and 16.8 %, respectively scoring 1 and 2. 34.5 % (score 3) and 12.6 % (4) and the highest, 26.9 % scoring 5 (poor quality).

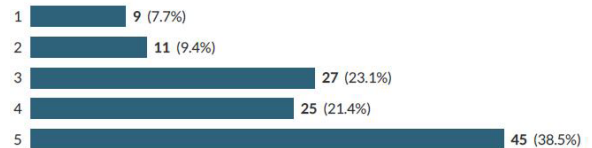
For manufacturing quality, the balance tilted slightly in a more positive direction, with 9.2 % (1) 21.8 % (2), 37 % neutral (3), but 14.3 % (4) and once again the highest figure of 17.6 % (5) denoting poor manufacturing quality. This result was reiterated by our gown review, where we noted that some disposable gowns were overlocked, incorporated internal and external waist/ neck ties, Velcro fastenings, ribbed cuffs and in one case a ribbed neckline (e.g. SubMed, Table 1).

Responses to Question 11.5, regarding the practicality of fastenings were very evenly distributed; the prevailing opinion being that fastenings are practical rather than impractical; 15.8 % (1), 21.7 % (2), 23.3 % (3) in contrast with 18.3 % (4) and 20.8 % scoring them as impractical.

If we look at the parameters in Question 12.1 light vs heavy, we immediately see that the majority of respondents estimate that gowns are light with 42.4 % (1) and 28 % (2), and only 5.1 % (4) and 2.5

% (5) considering them heavy. Almost half of the respondents to Question 12.2 soft vs stiff said their gowns were soft: 20 % (1) and 26.1 % (2) rather than stiff; 9.6 % (4) and 9.6 % (5). This is logical, as the disposable gowns are generally fabricated in non-woven spunbond polypropylene, such as the SubMed gown (Table 1). Over half the respondents to Question 12.3 waterproof vs absorbency (44.1 % score 1 and 21.2 % score 2) confirmed that their gowns were waterproof, rather than absorbent 8.5 % (4) and 1.7 % (5) which is to be expected in compliance with EN 13795 safety standards.

Q. 12.4 Breathability vs Non-breathability garnered a majority response of 69.9 % (38.5 % score 5 and 21.4 % score 4) compared with only 15.1 % confirming that their gowns were breathable; 9.4 % (2) and 7.7 % (1). (Fig. 6).



**Fig. 6.** Survey answers Question 12.4: What are the positive/negative aspects about wearing the gown: Breathable vs non-breathable?

## 2.2.4 Feelings of Protection and Risk

Of all the respondents to Question 13: Do you feel protected wearing your gown? 76.9 % felt safe when wearing their isolation gown, although 28 % did not. Those who felt protected described that the gowns covered all parts of the scrubs, their whole body, to at least knee-length, preventing the spread of microorganisms between patients and staff. They also noted the prevention of liquids from getting onto the uniform and body, as they are water repellent, as confirmed earlier (Q. 12.3). However, being “So plastic nothing can get through!”; “Very thin material that tears easily” and “It feels like clingfilm” were less positive in relation to safety.

Other comments relating poor protection included references to: “poor fit”; “too big and uncomfortable”; “arms are not protected” One person said that “arms got wet from the liquid used”, another noted that the gown was “too short and not covering the back” or “the whole body”. Other comments stated that their gown “Gets caught on things”; some “Some [reusable] gowns were very old” and “They do not cover the neck area, they are loose round the neck area. Very sweaty, sometimes seemed lined with polythene on

arms which sticks and irritates skin over forearms. Just awful.”

### 2.2.4 Sizes of Isolation Gowns and Their Impact on Performance

We were interested to discover what gown and dress size the survey participants usually wear, to make connections between the two wearing systems and the problems individuals face when wearing a gown size that is inappropriate.

The female participants indicated which (UK dress) sizes they wear, with the most common size, 33 % being 12 to 14 (M), followed by size 8 to 10 (S), worn by 24.1 %. Size 16 to 18 (L) is worn by 16.1 %, size 20 to 22 (XL) by 8.9 %, size 6 (XS) by 5.4 % of respondents, with the lowest number being 24 to 26 (XXL) at 1.8 %. As “Other” noted answers (10.7 %) are not important for the survey (e.g. I am a man; I do not wear women’s clothes) (Fig. 7).

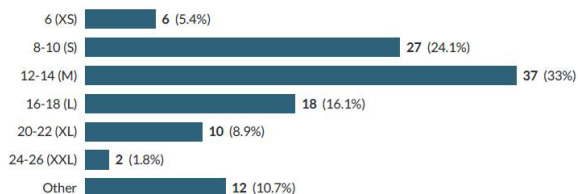


Fig. 7. Survey answers to Question 14: What womens' (UK dress) size do you normally wear?

Another question, 14b asked which men’s (UK dress) sizes they usually wear. The most common size was 40 to 42 (M) at 27.9 %, followed by size 44 to 46 (XL) worn by 18.6 % of survey participants. Size 42 to 44 (L) is worn by 14 % of, size 36 to 38 (XS) by 11.6 %, with sizes 38 to 40 (S) and 46 to 48 (XXL) each being worn by 7 % of the respondents. Other answers (14) are not important for the survey (e.g. I do not wear men’s clothes) (Fig. 8).

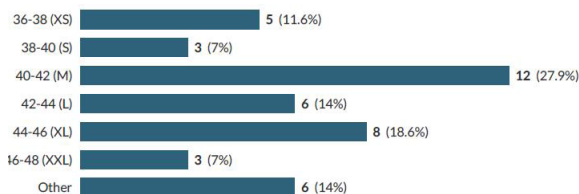


Fig. 8. Survey answers to Question 14b: What mens' (UK dress) size do you normally wear?

Although Medium was the most popular dress size for both women and men, large and one-size both scored 31 % in response to Question 15 (Fig. 9).

Other data relating to which size of isolation gown the healthcare workers wear included: M (23.3 %), XL (20.8 %), S (6.7 %), XXL (4.2 %) and XS (0.8 %).

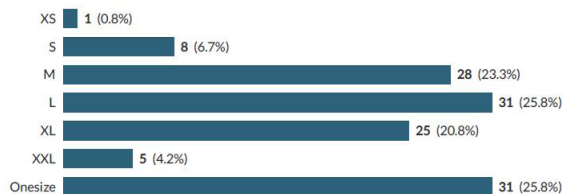


Fig. 9. Survey answers Question 15: What size is the isolation gown you normally wear?

If we compare the data for UK dress size 6 (XS) (Fig. 8) and 36 to 38 (XS) (Fig. 9) we can see that normally 6 women and 5 men wear this size. However, only 1 person, 0.8 % of the 123 women and men surveyed, wears a gown of that size (Fig. 10). Hypothetically, this suggests that 10 of the people who usually wear XS are wearing gowns too big for them. This situation was confirmed in the interview we had with the Clinic Manager from Diaverum, who stated that while most staff found the SubMed disposable gown comfortable in one-size, this was problematic for the smallest member of his team, who usually wore XS.

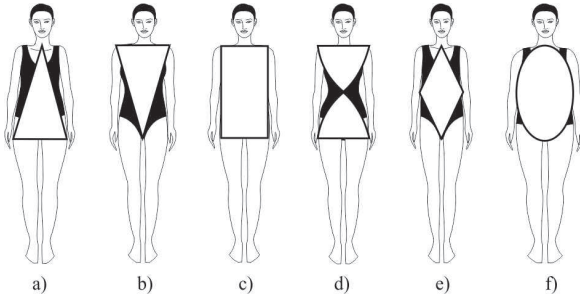
In reply to Question 16: “Do you feel that wearing this size of gown affects your performance?”, 53.8 % of the respondents answered yes and 46.2 % answered no, which they were asked to explain in 16a. Most comments were linked to discomfort during long shifts, of feeling too hot because of the gowns made them: “very hot and sweaty, causing dehydration!”

Predominantly reasons were linked to poor fit, due to only ‘large’ ‘XL’ or one-size being available although in one comment the issue was about the gown being too small. The excess volume of oversized garments was referred to by many, as was the length which proved hazardous in terms of tripping up the wearer. The following comment reflected on both extremes: “If they (gowns) are too tight, movement is restricted, and if they are too long, they are a tripping hazard.”

Other responses related to the impact on bodily movement, included: “The gown is too long” (as are the sleeves) “it is way too big”; “the gown interferes with work”; “sizes that sweep across the floor”; “made of too much material”; “is quite restrictive”; “some sizes are not available”; “can be baggy”, “Cumbersome”, “Usually too short in sleeve, but larger means too low at neck” and “It is the only size we have, it is very uncomfortable and difficult to move in as it is so large.”

### 2.2.5 The Relationship between the Shape of the Body and the Fit of Insulating Clothing

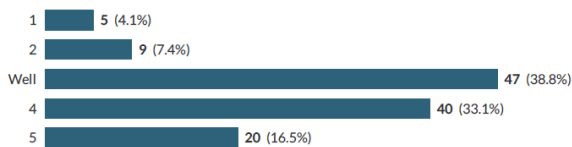
Question 17 asked “What body shape are you?” providing a link to sketches showing differences and emphasis of the body postures (Fig. 10). Most of them (34.2 %) are hourglass, rectangle (26.5 %) and oval (17.1 %). The fourth most common posture is triangle (8.5 %). Less common are trapezoid (5.1 %) diamond (4.3%), and inverted triangle (4.3 %).



**Fig. 10.** Survey answers Question 17: What body shape are you? Example for women body postures: a) triangle; b) inverted triangle; c) rectangle; d) hourglass; e) diamond; f) rounded. [20]

Answer about their height gives 103 people (out of 123 respondents). From these 103 validly filled questionnaires, we calculated that 6.8 % of the respondents have a height of 150 cm. Between 151 cm and 160 cm have 29.1 % of the respondents. Between 161 cm and 170 cm are 36.9 %, between 171 cm and 180 cm are 16.5 %, between 181 cm and 190 cm are 8.7 % and between 191 cm and 200 cm are 1.9 % of the respondents.

Replies to Question 19 indicated gown length preferences as: calf-length (38 %), knee-length (33.9 % each), slightly less (28.1 %) like full-length. Question 20 around ‘fit’, confirmed that only 11.5 % (scores 1 and 2) of respondents rated their isolation gowns as being too small. 38.8 % of them say that they fit well but significantly, almost half, 49.6 % considered their gowns to be ‘too big’ comprising 33.1 % (4) and 16.5 % (5) (Fig. 11).

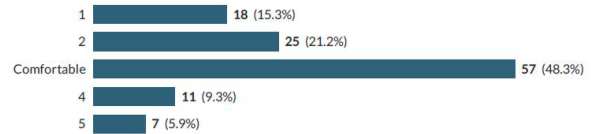


**Fig. 11.** Survey answers to the question How does the isolation gown fit you: too small vs too big?

### 2.2.6 Design Details

Details are very important. We can find many different variants of them on the market and the questionnaire particularly exposed necklines, cuffs and fastenings.

Cuff and sleeve: A cuff with thumb loop was the most desired variant (32.5 %), as well as elastic (30 %) and knitted rib (28.3 %). To the question “Is your cuff lose fitting vs tight fitting”, 56.8 % of respondents said it was comfortable, 23.7 % said it was too loose and 19.5 % said it was too tight. To the question “Is your sleeve too long or too tight?” 48.3 % of all responses are comfortable, 36.5 % are too long, and 15.2 % are too tight (Fig. 12). Our gown review reinforced these observations, with the predominantly one-size garments being generally designed to fit a male over the height of 6 foot, resulting in sleeves and overall gown length being proportionately too long.



**Fig. 12.** Survey answers to the question: Is your sleeve too long vs too tight?

Neckline. The respondents’ gowns had a neckline finished with wide binding (27.9 %) or narrow binding (52.1 %) and no one wore a gown with a hood. In response to “Is your neckline gaping vs tight?” 48.7 % wrote that it was comfortable, 37 % are gaping and 14.3% found them tight.

Fastenings. When asked “What kind of fastenings does your gown have?” most (35.1 %) said they tie it at the neck, tie around the waist, or hidden inside the gown, at the waist. 33.3 % of respondents have a Velcro fastening at the back-neck, 28.1 % of respondents wear an open-back gown. Only 6.1 % wear three ties at the centre back.

Ease of movement across back vs restrictive movement across back; 65 % of respondents wear gloves with easy movement on the back. 21.4 % choose neither easy movement nor restrictive movement. 13.6 % find movement across the back restrictive.

Easy movement vs restrictive underarm movement; 58.1 % wear gowns with easy movement from underarm, 14.5 % perceive restrictive underarm movement, and another 27.4 % are neutral (Note 3).

Easy movement at the waist vs restrictive movement at the waist; 61.8 % feel easy movement at the waist and 10.4 % perceive only restrictive



movement at the waist. The remaining 27.8 % chose a value of 3 between these two options.

### 2.2.7 Further Comments from Participants: Free Text Responses

Finally, we asked for any other comments on the daily experience of wearing the PPE isolation gown and invited suggestions for improving the design. Most of their responses have already been mentioned as comments on specific questions. What they revealed must be highly irritating to our respondents. We highlighted the most disturbing observations as follows: “Hot feeling.” / “Too warm in hot weather.” / “Too hot.” / “Uncomfortable in warm weather.” / “Very sweaty – stick to you.” / “Too plastic.” / “Can become very hot and sticky if the room is warm.” / “Make them less tearable and less warm.” / “They are so hot and sweaty! Would love to wear more breathable gowns!”

Breathability. They want to have breathable fabric, possibly with stretch. / “Make breathable especially form elbows down uniform scrubs tend to absorb sweat but elbow down doesn’t as gown directly touches bare skin.” / “It can get very warm wearing a plastic gown however I do like that it’s waterproof.” / “The plastic gowns are unbearable when it’s hot. I sweat so much in them and then become dehydrated; They are also terrible for the planet.” / “Breathable material appreciated as gown can get quite hot the longer, they are worn.”

Improved fabrication for cuffs. “Replace wrist cuff material that irritates the skin.”

Size. “Poor choice of sizing. Bigger size needed vs overall length too long” / “too long sleeves.” / “Sleeve with thumb loop always too short.” / “Would like to have different sizes available other than extra-large at the time.” / “Because of excess fabric I can the gown on drawers, handles and the like. If small gowns are unavailable, I risk tripping up whilst wearing large gown. Gowns are not designed for petite wearers.” / “Sometimes they are a little too long for short people, I sometimes trip over them.”

Style. “I like the theatre style gowns.”

Disposable vs reusable. Some prefer disposable, so it goes straight in the bin. / “Disposable rip easily.” / “Prefer to wear plastic ones despite being hot all the time.” Persons like to wear these through rather than the reusable one as the reusable ones when exposed to liquids it gets soaked and it may be difficult to untie the ties at the back. / “I find much more comfortable wearing the fabric gowns to plastic & they are better

for the environment.” / “A breathable material is very important. Since the pandemic started, we have been using reusable washable fabric gowns rather than disposable plastic gowns and I much prefer the environment consequences of this.” / “We just have to use what is available. Majority of the time is reusable but sometimes we have to use disposable which are not nice to wear due to being sweaty, hot and non-breathable.” /

Neckline. “Adjustable neck.” / “They are loose round the neck area.”

Fastening. “The tie fastening at the back isn’t practical it just comes apart, not secure enough.” / “I would prefer adjustable Velcro tabs rather than ties.” / “Remove the tie at the back maybe have Velcro.” / “Could have bigger ties as being big and tall makes it hard to tie.”

Other comments. Two persons exposed the problem of pockets. From the reason of equipment (radios, phones, keys, algorithm cards) that they use, the gowns they have does not support them by works need. They would like to have “Some sort of pocket or waistline access who prevent us having to lift whole gown down.” Other respondents wrote: “There is nowhere to attach a pen or pen torch.”

## 3 RESULTS

Analysis of research from articles, models on the market, interviews with clinical and procurement leaders, and surveys was important in identifying key design issues.

Based on findings from all the methods but particularly ‘wearer experience’ as identified by the survey participants, we discovered both the positive and negative aspects of the gowns on the market based on different criteria. These include: the specifics of the workplace; the posture and height of the person; the length of time the gown is worn; the different qualities of construction and the materials, and personal opinions based on the experiences of our respondents. Some of the responses were a little contradictory, reflecting contrasting gown provision and working hours/ conditions, but there was consensus on key issues which informed our further design work.

The most common issues were: 1. the issue of heat stress due to non-breathable fabrication; this problem is related to the use of water repellent materials, also revealing the dilemma of using disposable or more sustainable solutions in reusable gowns; 2. inappropriate sizing; 3. garment details causing discomfort, donning or doffing issues.

### 3.1 How to Design Gowns That Prevent Overheating?

The strongest consensus regarding the gowns in use was their heat inducing properties. One respondent said of the fabric, “The plastic gowns are unbearable when it’s hot. I sweat so much in them and then become dehydrated. They are also terrible for the planet.” This finding, borne out by the literature [14] requires serious consideration of materials. In our further work we want to offer a better, more sustainable solution. The aim is to source a lighter weight textile, that still provides the necessary protection against fluid. There is also the possibility that the material for the back of the gown could be lighter than for the front. We are considering polyester/ carbon (99 % / 1 %) textiles with special fluorocarbon coatings, which can be washed in temperatures (71 °C) to thermally disinfect the garment by killing off all viruses and bacteria. With washing and reusing we can help reduce the impact on the environment. Another challenge to enhance breathability and lightness lies in the design, which can also be explored to reduce discomfort.

### 3.2 How to Improve Sizing Problems

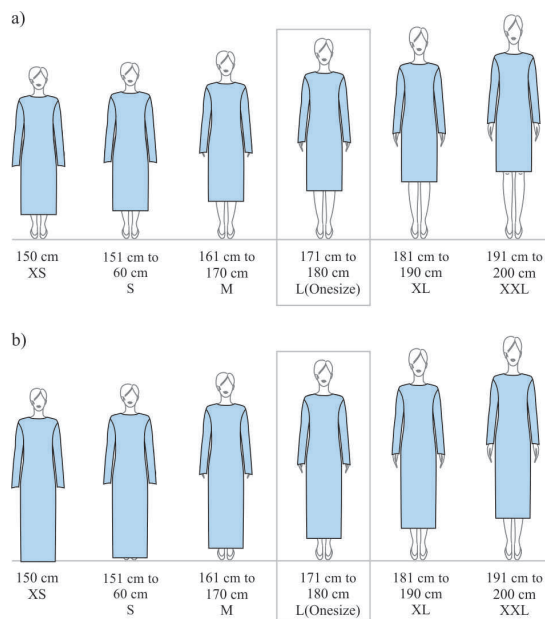
Sizing is problematic, particularly with regard to the most commonly available “one-size-fits-all” gown. According to a review of the models we procured, the large (L) gown is the most common equivalent to One-size and as we can see, the One-size is the most common size worn by the survey participants (31 %). “Large” offers the best fit is for a person with a height of 170 cm to 180 cm, as highlighted in Fig. 13. Based on the survey responses, we drew the other heights of the respondents, which are indicated below each picture in cm.

To better imagine the kind of problem caused by sizing, especially for smaller-sized users, two models corresponding to the shortest (106 cm - model 1) and longest (129 cm - model 4) length of gowns, are shown in Table 1.

Through sketches we have simulated the same dress on different body heights; the shortest model marked as sketch line a) and longest marked as line b).

We can see that the smallest model length of 106 cm (Table 1) shown in Fig. 13a, is a suitable size/ length for a body height of 161 cm to 180 cm, but too big/ long for the shorter (150 cm to 160 cm) and too short for the taller (181 cm to 200 cm) individuals. The comparison is more extreme (Fig. 13b) when illustrating the longest model length of 129 cm, (Table 1). Users indicated in the survey that the gowns are obstructive during work. When we look at the longer

models on smaller sizes, they extend to the floor. This evidences the need for a wider range of sizes to meet the different physiological characteristics of users.



**Fig. 13.** Sketches of the most common sizes of users and visualization of the problem of wearing one-size gowns, based on data in Table 1; a) the shortest model (length of gown 1) 106 cm and; b) the longest model (length of gown 4) 129 cm

### 3.3 Details That Can Improve User Comfort and Practicality

Gown details such as necklines, fastenings, cuffs can be considered for potential improvements. For example, tight or loose necklines can irritate or protrude from the body; simple gown fastenings for easier donning and doffing are desirable and variations to cuffs, incorporating straps, Velcro or snaps should be considered.

A few respondents would like a pocket: “Some sort of pocket or access to prevent us having to lift whole gown up [to access scrubs]” Another respondent wrote: “There is nowhere to attach a pen or pen torch.”

Findings from all the information referenced in the article influenced the further design development stage of the research.

### 3.4 Design and Development of Gowns

#### 3.4.1 Analysis of Information and Design

Once all the qualitative and quantitative information was analysed and defined, we began developing the gown concepts.

Key issues influencing the design were identified as:

- the positive and negative aspects of gowns on the market,
- different roles and workplace scenarios,
- the posture and height of the person,
- size/ length of the gown,
- the varying quality (disposable/ reusable) of material, and
- personal opinions based on the experiences of our participants.

Some of the information was contradictory (e.g. sleeves too short / long), but in general we were able to concentrate on how the key issues could be mitigated through redesign.

The priority was to be more sustainable [17], so we decided to develop only reusable gowns, in more breathable fabrications. The planet is dealing with a huge amount of clinical waste. And while it is understandable that at the beginning of the pandemic, disposable gowns offered the most expedient solution to the needs of healthcare organizations, we now need to consider a more sustainable approach for the future use of PPE, including gowns [17].

In the design stage we particularly paid attention to the development of the functional form and details. The process of designing and developing functional clothing is based on the results of an objective evaluation of the user's requirements, and therefore tends to be complex and iterative [21]. Gupta [21] also highlights that in addition to the primary requirement of functionality, the wearer's needs are also related to the physiological, biomechanical, ergonomic, and psychological properties of the garment, which have different correlations depending on the intended use. An ergonomic design process involves the following steps: "selection of materials, determination of size and fit, pattern making, assembly and finishing" all of which were adhered to in our own methodology. This approach is relevant for the design of surgical, PPE gowns and clothing worn by healthcare workers in general to support protection, comfort and wellbeing. As evidenced in the survey analysis, the length of the gown and sleeves, availability of sizes, fastenings and feeling hot in composite, non-breathable textiles were commonly mentioned as hindering the daily working experiences of healthcare workers.

Initial sketches (Fig. 14) included some useful elements for further development of the selected models. Ideas for the neckline, front closure and various cuff solutions are being sampled and tested as details and part of gown prototypes.



Fig. 14. Initial sketches of gown design concepts

Different design approaches to necklines (Fig. 15), cuffs (Fig. 16), gown fastenings (Figs. 17 and 18) an inner pocket (Fig. 17c) are illustrated below.

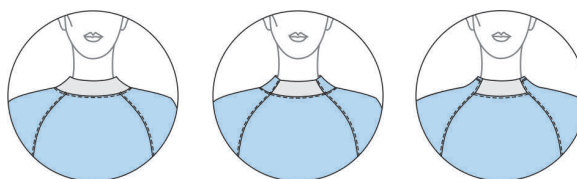


Fig. 15. Initial sketches of neckline finishes

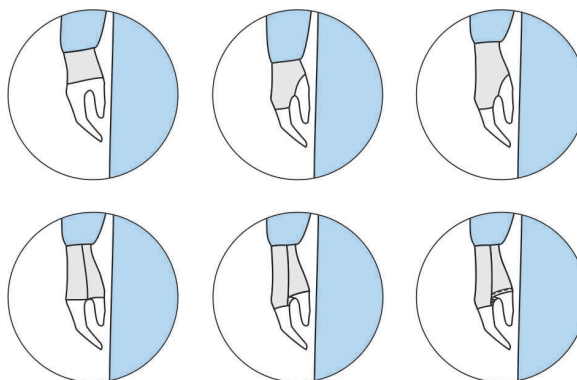
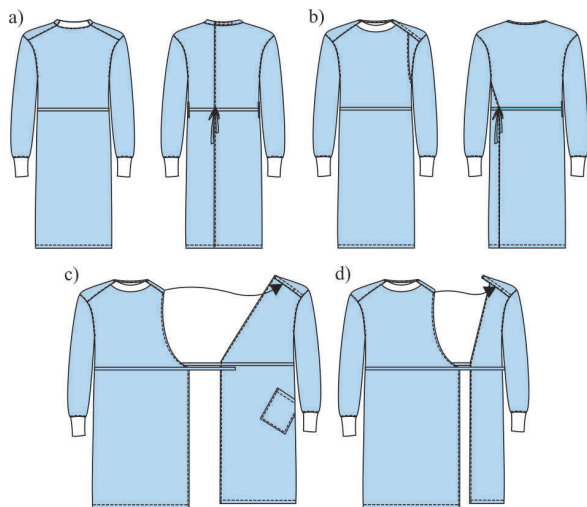


Fig. 16. Technical sketches of different cuff solutions

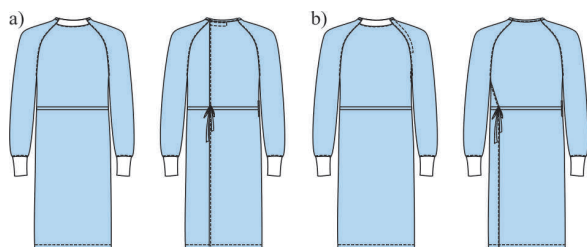
The development of pattern and detail designs is encompassing pattern cutting using traditional approaches informed by standard body measurements body shape index (BSI) and existing gown dimensions. The iterative sampling of cuffs, necklines and fastenings is also being undertaken.

The combination of a knitted rib neckline and cuff is common to all models, based on issues relating to comfort and safety. The style of the sleeves differs between the models e.g. set-in (Fig. 17) and raglan sleeves (Fig. 18) and fastening details on the centre-

back (Figs. 17a and 18a) and left-back (Figs. 17b and 18b).



**Fig. 17.** Variations of Prototype 1 and 2 with set-in sleeve; a) Velcro back-neck closure and waist-tie at centre-back; b) front closure with side fastening and double-layer front; c) fastening variations and inner pocket; and d) double-layer front with narrower under-layer



**Fig. 18.** Variations of Prototype 3 with raglan sleeve; a) back closure with neck Velcro and waist tie at centre-back; b) front closure with waist tie at back-left side

#### 4 CONCLUSIONS AND FURTHER WORK

Since the outbreak of COVID-19, a shortage of suitable PPE has resulted in healthcare workers wearing disposable, “one-size-fits-all” isolation gowns, compromising comfort and safety. Oversized, ill-fitting gowns impede freedom of movement and increase body temperature and the risk of viral transmission. Clinical procurement and acute care leaders have expressed the need for more sustainable, reusable, individual-size PPE gowns fabricated from washable textiles to enhance the experience of healthcare workers while mitigating infection risk and reducing clinical waste.

The main purpose of this research was to identify the issues experienced by healthcare workers experience when wearing disposable, “one-size-fits-

all” PPE isolation gowns when treating patients with coronavirus. The research findings, together with detailed product information, informed the design and development of prototypes. All results will be used as the basis for the next step.

We have developed various details and models that represent a range of possible solutions in practice.

The use of the information disclosed in this study is important for further work. The “one-size-fits-all” sizing system needs to be considered for all users, who often suffer from working in inappropriate gowns. Additional size options (e.g. XL to 3XL) should be more widely available and are being developed and trialed through this research.

We designed closures, cuffs and necklines with more options (some presented in sketches). By prototyping these solutions as creative experimental research, employing range of scientific and material methods and data [5], [13], [14], [17] and [19] to enhance the ergonomic and technological sustainability of future gowns [9] and [21].

By designing reusable gowns from a textile developed specifically for surgical high performance textiles heat-reducing, breathable solutions are possible.

A range of alternatives are offered that add both utility and protective value to the designs. Details added value in the form of soft knit on the collar, an extended knitted rib with a thumb loop, a hidden pocket that is not directly visible, variations in closures and lengths offered.

The further development of the prototyping and production models is currently being undertaken with a PPE manufacturer, ensuring the gowns are EN 13795 compliant and CE accredited. A laundry provider will coordinate the testing of the multiple sized reusable prototypes (washed/worn up to 70 times) with different nursing teams treating patients with COVID-19 across various healthcare organizations in the UK.

#### 6 ACKNOWLEDGEMENTS

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The key data underpinning the paper are published within it. The online survey remains open, the results of which will be available with the entire data set at the end of the project on 05/01/2023, DOI: 10.5281/zenodo.6394461.

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