ACKNOWLEDGMENTS

The authors would like to thank:

- All those who provided eye protection samples including those from the project team and the wider WHO research programme;
- Terry Gee of HSE workshops for building the manikin head test rig and creating the absorbent material sample templates.

KEY MESSAGES

In the current coronavirus pandemic, the use of personal protective equipment (PPE) is an important component in the strategy to control exposure to the virus and resultant disease transmission.

Face shields used in healthcare, industry and by members of the public either provide a protective barrier for the facial mucosa (eyes, nose and mouth) or an outer layer of protection to face masks or respiratory protective equipment.

Face shields are currently designed and tested as eye protection according to BS EN166:2002 or equivalent standards, but they are not assessed for their ability to provide full protection of the facial mucosa from droplets such as would be generated by a human cough.

A method was developed and implemented to assess the level of protection to the wearer afforded by ten different face shields against droplets from a simulated human cough.

The results demonstrated that the protection afforded by each face shield could vary depending on the head size. Breaches were greater in number and at a higher level of droplet contamination with face shields on the large head.

None of the face shields tested totally eliminated exposure, and there were differences in the level of protection afforded by each. The orientation of the head influenced the level of protection and in some instances this could be associated with design features.

The methods developed here could be adapted for use in resource-limited countries by using recycled spray bottles to produce visible dye droplets and using a pump to simulate inhalation.

EXECUTIVE SUMMARY

Background

In the current coronavirus pandemic, the use of personal protective equipment (PPE) is an important component in the strategy to control exposure to the virus and resultant disease transmission. This includes the use of face shields in healthcare, industry and by members of the public, either to provide a protective barrier for the facial mucosa (eyes, nose and mouth) or to provide an outer layer of protection to face masks or respiratory protective equipment. Face shields are currently designed and tested as eye protection according to BS EN166:2002 or equivalent standards, but they are not assessed for their ability to provide full protection of the facial mucosa from droplets such as would be generated by a human cough.

Aims

The aims of this project were:

1. To develop and implement a robust method to measure the protectiveness of various face shield designs against a droplet challenge.
2. To suggest adapted test methods to enable lower-resourced countries to undertake their own testing with apparatus that is readily available.

Methods

A cough simulator was designed and built, based on a previously published method, to mimic the volume, velocity and particle size characteristics of a human cough. This comprised a piston to deliver pressurised air, with an airbrush that introduced an aqueous solution of fluorescein into the airstream. The resulting ‘cough’ was directed toward a manikin head wearing a face shield and mounted on a rig that allowed it to tilt forward and back and side to side. Two different sized heads were used to represent the majority of head sizes in the international adult population, and were connected to a breathing machine. The ‘cough’ was timed to coincide with inhalation of the manikin, thus presenting a worst-case scenario.

Deposition of simulated cough droplets on a non-fluorescent absorbent template covering the eyes, nose and mouth regions were visualised under Ultra Violet (UV) light. The extent of droplet deposition was classified as undetectable, low, medium or high, and also respectively given a numerical value 0, 1, 2 or 3.

In total, ten face shields were tested; one each from the UK National Health Service and the WHO PPE stockpiles, two from Nigeria, five from Brazil and one from Tanzania made from recycled material. Each face shield was tested in triplicate, with seven different head orientations.

Findings

A method was developed and implemented to assess the level of protection afforded by different face shields against droplets from a simulated human cough.

The results demonstrate that the protection afforded by each face shield could vary depending on the head size. Breaches were greater in number and at a higher level of droplet contamination with face shields on the large head.

None of the face shields tested totally eliminated exposure, and there were differences in the level of protection afforded by each. The orientation of the head influenced the level of protection and in some instances this could be associated with design features. For example, breaches occurred where face shields were more open at the bottom if the head was tilted back.

Across all 10 face shields, on the small manikin head, position 4 (left looking up) and position 6 (right looking up) gave the highest breach score although mostly as a consequence of low level breaches, while position 3 (front looking down) resulted in the largest number of high level breaches.

On the large manikin, head position 4 (left looking up) again gave the highest breach score, while positions 2 (front looking up) and 6 (right looking up) also gave high breach scores. All three of these positions resulted in large numbers of high level breaches.

The methods developed here could be adapted for use in resource-limited countries by using recycled spray bottles to produce visible dye droplets and using a pump to simulate inhalation.

CONTENTS

1 INTRODUCTION

This project was a collaboration between University of East Anglia (UEA), the Universities of Lagos, Nigeria and Sao Paulo, Brazil, Public Health England (PHE) and the Health and Safety Executive (HSE), funded by the World Health Organisation (WHO). WHO wanted to develop robust methods to measure the protectiveness of various face shield designs against a droplet challenge, and to transfer that knowledge to enable lower-resourced countries to undertake their own testing with apparatus that is readily available.

There are advantages to the use of face shields, but limitations also exist. For example, face shields are currently designed and tested as eye protection according to BS EN166:2002 or equivalent standards, but they are not assessed for their ability to provide full protection of the facial mucosa from droplets such as would be generated by a human cough. Whilst some manufacturers state that the face shields are only for splash protection, others do suggest some protection against airborne droplets.

Phases one and two of the project, covered by this report, aimed to evaluate the protectiveness of a range of face shields at protecting the wearer against a droplet challenge mimicking a human cough. This was achieved by the following objectives:

1. Design and build a manikin test rig, develop methodology for cough simulation and build a simulator.
2. Demonstrate using a laboratory model, the protectiveness of different face shield designs at protecting the wearer against a droplet hazard.
3. Disseminate the findings to inform policy within country and with WHO.

The third phase of the project aimed to conduct questionnaires in Brazil and Nigeria to determine the circumstances in which face shields are worn and the wearers' perceptions of protectiveness, practical wear-ability etc. The findings from this phase of the project will be reported separately.

2 METHODS

2.1 Selection of face shields for testing

Ten face shield designs were tested for this project. Photographs of each face shield can be found in Appendix A. The face shields chosen were representative of those entering the global healthcare supply chain and used in communities worldwide. In summary they were as follows:

- HSE obtained one face shield from the UK healthcare personal protective equipment (PPE) supply chain (sample reference PH20194/02).
- HSE received five face shield models from Brazil (sample references PH20194/15 and PH20194/20 – PH20194/23).
- HSE sourced one face shield model in UK on the understanding that it is used widely in Nigeria (sample reference PH20194/16).
- HSE received two face shields from WHO, including one face shield from Tanzania made of recycled materials (sample reference PH20194/17) and another from the WHO PPE stockpile (sample reference PH20194/18).
- HSE received one face shield model from Nigeria (sample reference PH20194/19).

2.2 Dimensions and fit of the face shields

2.2.1 Dimensions

Each face shield was removed from its packaging and assembled where applicable. The following dimensions were measured before mounting the face shield on a head. See Figure 1 for a summary of the measurements:

1. The thickness of the headband at the point that would be closest to the centre of the back of the head when worn.
2. The thickness of the foam i.e. the width of the side attached to the face shield, where applicable.
3. The depth of the foam or size of gap between the face shield and forehead.
4. The width of the visor (face shield window) at the top.
5. The length of the visor from the top to the bottom along the centre line.
6. Total length of the face shield including the headband.

All measurements were made with a steel ruler or flexible tape measure where appropriate and are therefore accurate to ± 1 mm.

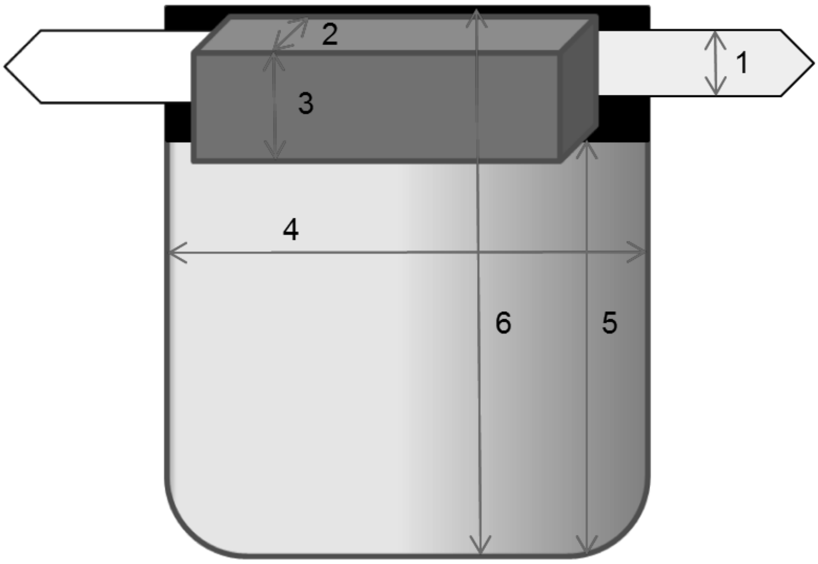


Figure 1 Measurements taken for each face shield

2.2.2 Fit

Two manikin heads were chosen for the face protection challenge studies; representing male and female head forms from different global regions. The larger 'Sheffield Head' had a circumference of approximately 59 cm and the smaller head had a circumference of approximately 52 cm. These were used to measure the extent of coverage of the face as follows. Each face shield was put onto the manikin heads following manufacturer instructions, where provided. The distance between the edge of the face shield and the base of the ear was measured on each side using a manufacturing seam on the manikin head which goes through the top of the ear to the base of the lobe as a guide (Figure 2). Data are presented as the mean of the left and right side distance.

Other observations made about the comfort and wear-ability of the face shields during this exercise or the droplet challenge tests were also noted.

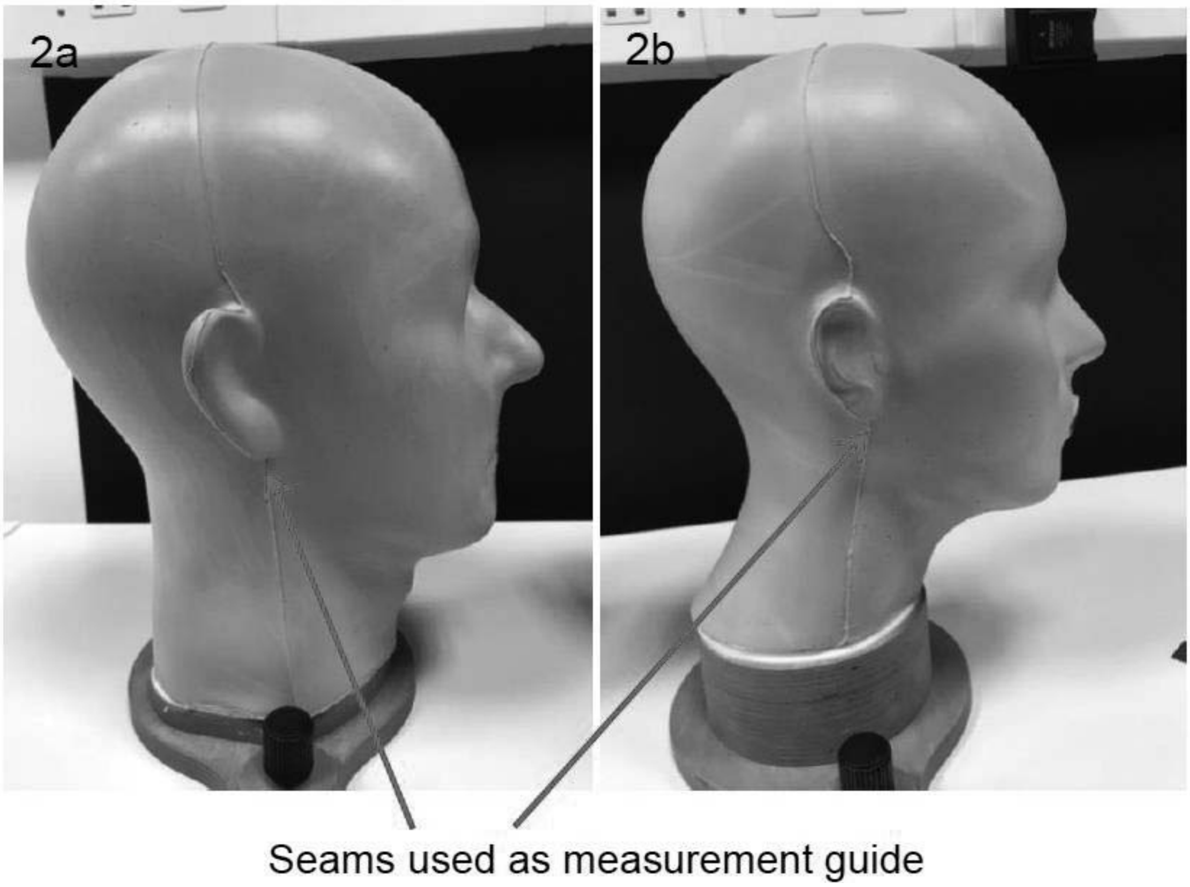


Figure 2 Large (a) and small (b) manikin heads (IMG0963 and 0964)

2.3 Breathing manikin test rig

A bespoke test rig was constructed by HSE workshops following the design described in BS EN166 (Figure 3). Manikin heads were mounted on a movable platform, enabling them to be tilted forward and back and rotated side to side and locked in the required position.

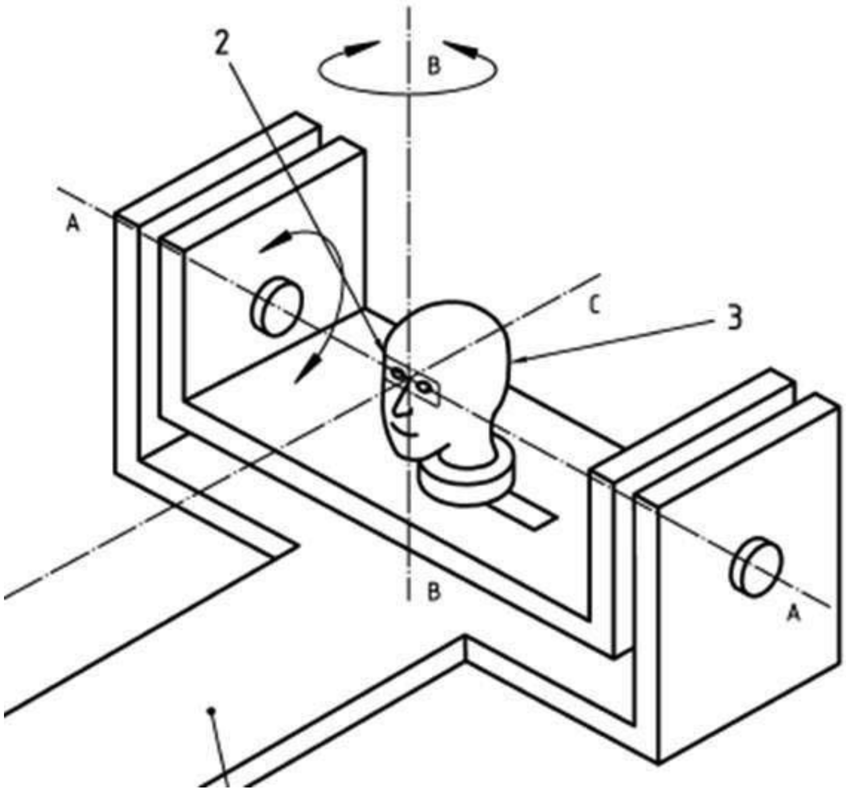


Figure 3 Diagram of the manikin head rig with axes A, B and C labelled (Image adapted from BS EN166:2002)

Tubing joined a connection beneath the neck of the head to a breathing machine (Inspec International Ltd) operating at a breathing rate of 20 breaths per minute with a 'lung capacity' of 2 litres.

2.4 Cough simulator

HSE's cough simulator was based on an existing design described by Lindsley et al. (2013). Lindsley et al. based their cough simulator design on flow rate measurements of coughs from 47 human subjects with influenza (Lindsley et al. 2010).

Each volunteer's cough was different, but all had a general flow versus time profile rapidly reaching a peak and then tailing off (Figure 4).

The basic design of HSE's cough simulator relied on a 'drive cylinder' and a 'lung cylinder', as shown in Figure 5. Both sides of the drive cylinder were pressurised before valves were opened simultaneously to depressurise the front end and initiate the cough.

The cough simulator ejected 4.2 litres of air through a 'mouth' opening. The flow rate against time profile was measured by a spirometer and found to correspond to the first 1.3 seconds of the graph in Figure 4.

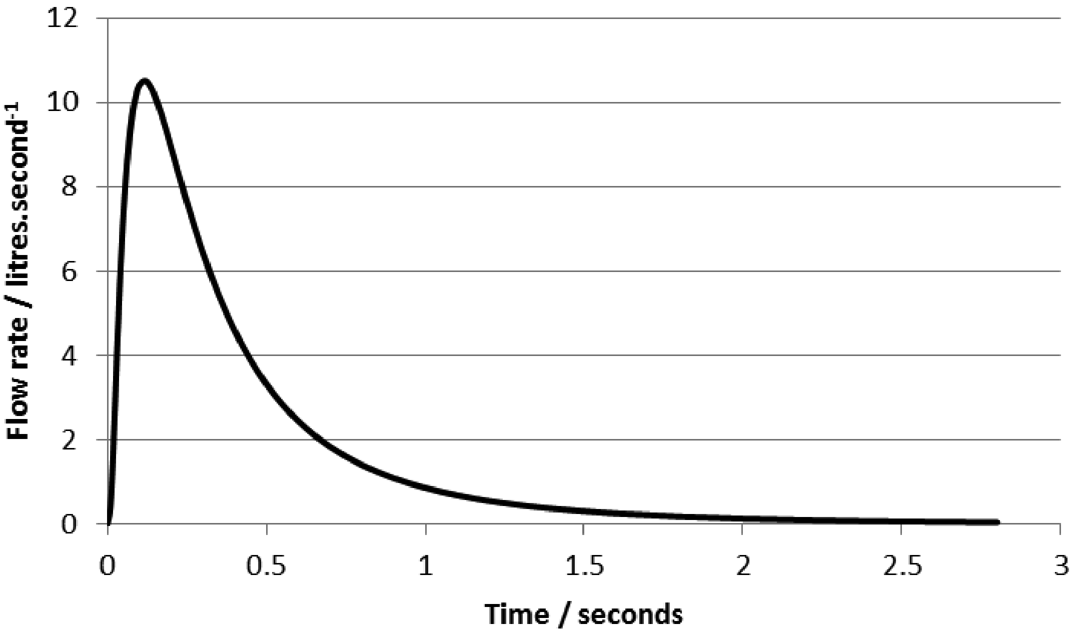


Figure 4 Target profile of cough simulator based on flow rate measurements of coughs from 47 human subjects with influenza made by Lindley et al. (2010)

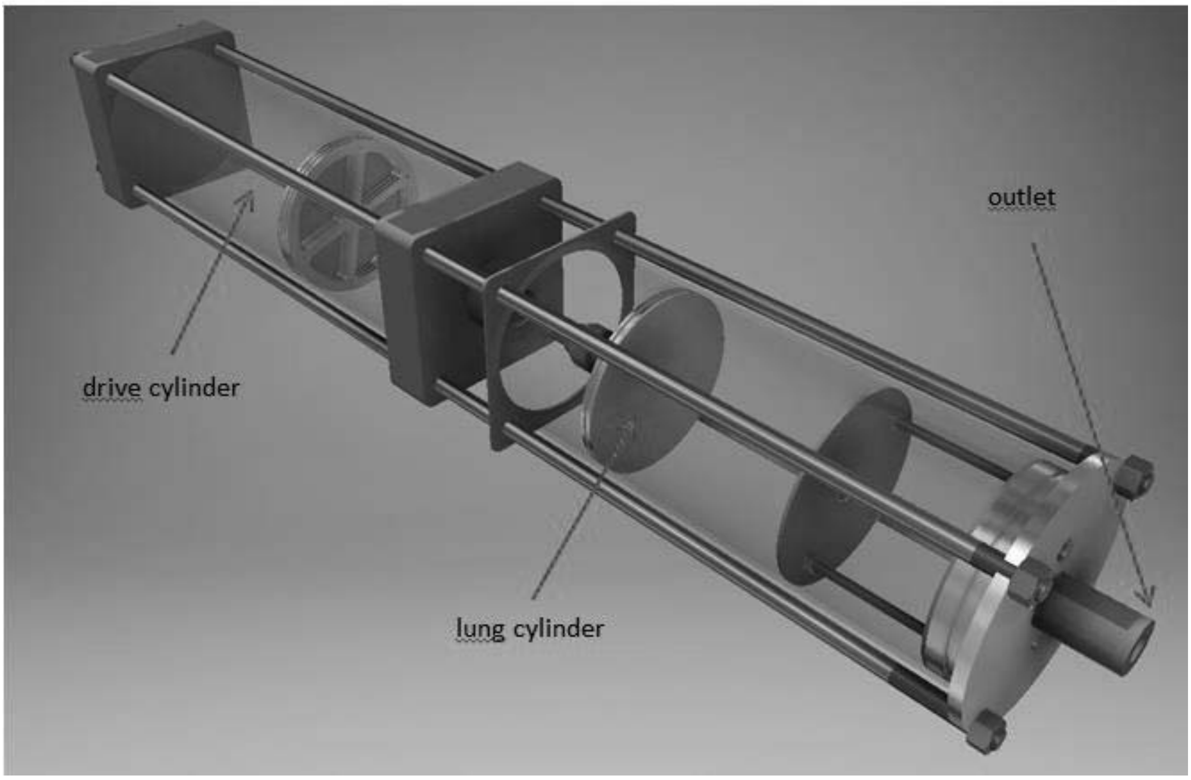


Figure 5 Design of the HSE cough simulator with the barrels transparent

The outlet (Figure 5) was connected to a plastic ‘T’ piece with branches running perpendicular to the cylinders. At one end of the ‘T’ piece a Badger Airbrush model 200 (shown later in Figure 7) delivered a solution of 0.1% fluorescein in water. The airbrush sprayed droplets of the solution into a plastic pipe (1.1 m length x 0.04 m diameter) which was connected to the other side of the 'T' piece and faced the manikin head. The combination of the air flow rate from the cough simulator and the droplets produced by the airbrush simulated a human cough. The simulated cough containing fluorescein solution was directed towards the breathing manikin described below.

2.5 Challenging the face shields with droplets

Templates were laser-cut from laboratory Benchkote (Cytiva Whatman Benchkote Surface Protector, Fisher Scientific), an absorbent paper fibre-based material with a plastic backing, which had previously been shown to be non-UV fluorescent. Two templates, one for each manikin head size, were designed to capture deposit of fluorescein droplets on the face of the manikin head, the templates being delineated into three regions: eyes, nose, mouth. The templates were pre-labelled according to the face shield model, manikin head size and position. The appropriately sized template was placed over the face of the manikin head (an example shown in Figure 6) and secured in place using adhesive tape over tabs at the sides of the eye and mouth sections.

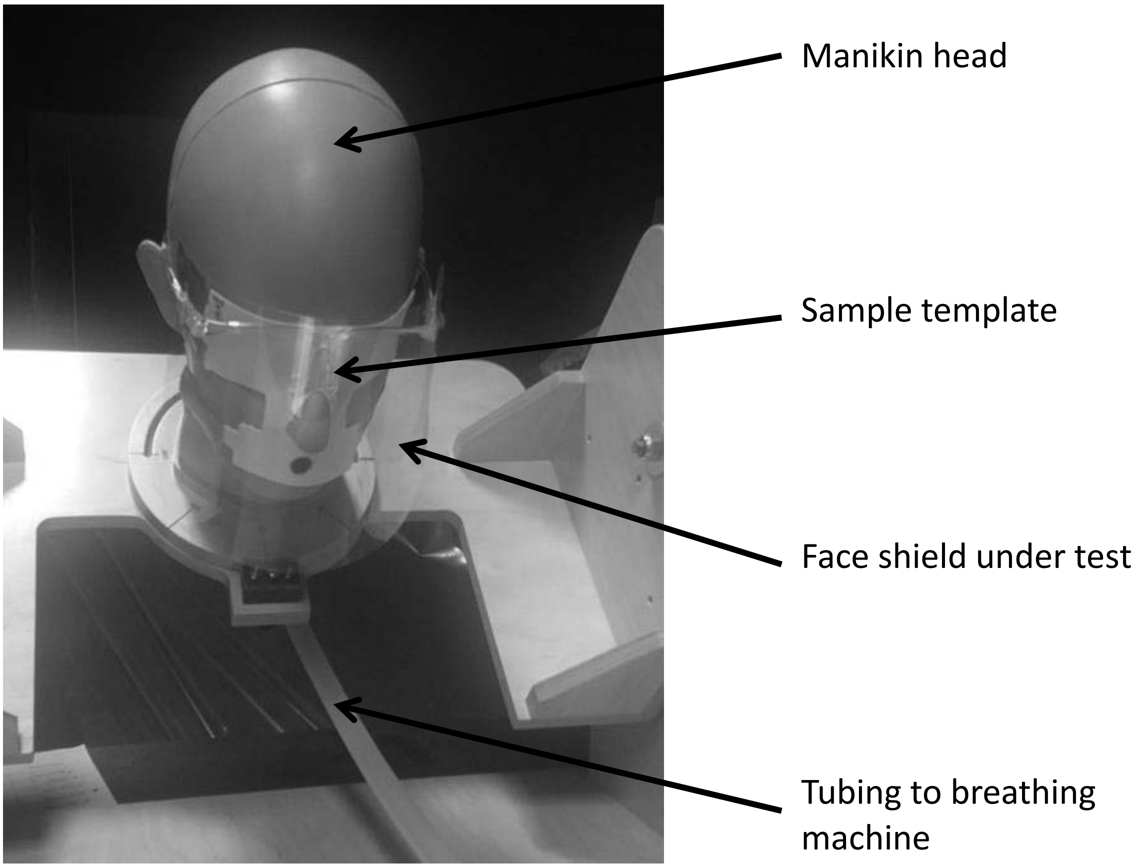


Figure 6 A sample template fixed to the manikin head whilst attached to the test rig. The manikin head is attached to the breathing machine via tubing at the neck.

An ultraviolet (UV) light (Titan365 UV LED, UV Light Technology, Birmingham, UK) was used to confirm that the sample was devoid of any fluorescence before proceeding. The face shield was then mounted on the head following the manufacturer's instructions and the manikin head was adjusted to the required position.

The cough simulator was positioned 60 cm in front of the manikin head along axis C in Figure 3 and level with the eyes (see example in Figure 7). Preliminary experiments delivering a cough to the manikin heads without face shields in place confirmed the even distribution of droplets across the templates.

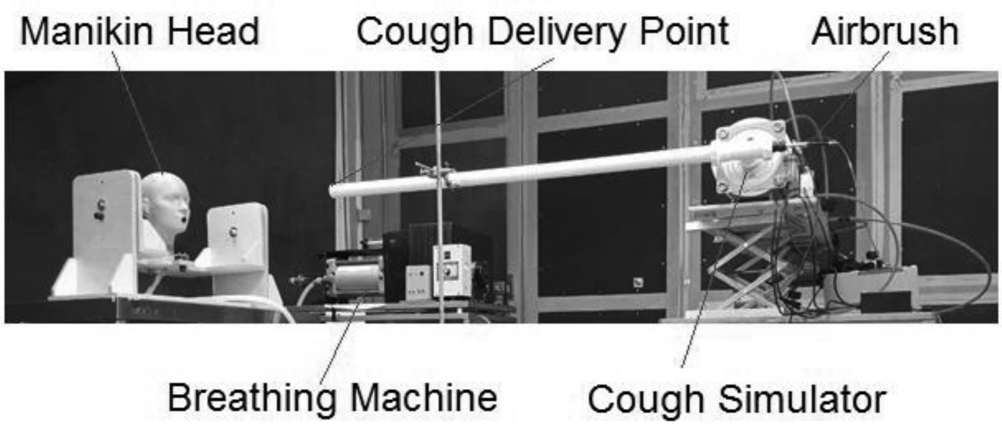


Figure 7 Cough simulator positioned in front of the manikin head rig and breathing machine to the side

The 'cough' was synchronised with the inhalation phase of the breathing cycle and repeated three times. The reason for the repetition was two-fold. Firstly, it had been determined in preliminary testing that a single 'cough' would deliver insufficient droplets for accurate measurement, therefore multiple coughs would be required. It had been observed that typically when humans cough it is often in bouts of three, therefore it was decided that each challenge would comprise three 'coughs'. After three consecutive 'coughs', the face shield was removed and the template was then taken off the manikin head, handling only the tabs/tape to avoid cross-contamination of the deposition areas, and then replaced with a new sample. Exposed samples were removed from the test area and stored in a clean space ready for further analysis.

Each test was conducted with the following manikin head positions, using a new absorbent material sample template but the same face shield, taking care not to cross contaminate the sample:

- Position 1: Facing forwards with the head face on.
- Position 2: Facing forwards and rotated 45 degrees backwards about horizontal axis A (front and looking up).

- Position 3: Facing forwards and rotated 45 degrees forwards about horizontal axis A (front and looking down).
- Position 4: Rotated 90 degrees to the left about vertical axis B and rotated 45 degrees backwards about horizontal axis A (left and looking up).
- Position 5: Rotated 90 degrees to the left about vertical axis B and rotated 45 degrees forwards about horizontal axis A (left and looking down).
- Position 6: Rotated 90 degrees to the right about vertical axis B and rotated 45 degrees backwards about horizontal axis A (right and looking up).
- Position 7: Rotated 90 degrees to the right about vertical axis B and rotated 45 degrees forwards about horizontal axis A (right and looking down).

Once all sample positions had been tested for each face shield, the room was then ventilated to remove any fine particles from the air.

Three replicates of the protocol were undertaken with both the large and small manikin heads attached to the manikin rig and using each of the test face shields.

2.6 Sample analysis

Each sample was viewed under UV light and the presence or absence of fluorescent deposits in each region of the sample was separately recorded i.e. the eyes, nose and mouth.

This analysis weighted one single drop of fluorescence equally to if the area was totally contaminated.

It was considered useful to additionally classify the level of contamination in each area of the sample as ‘Low’, ‘Medium’ or ‘High’. One researcher was assigned this task in order to reduce the variability of this subjective analysis. Examples of each of the three categories are shown in Figure 8.

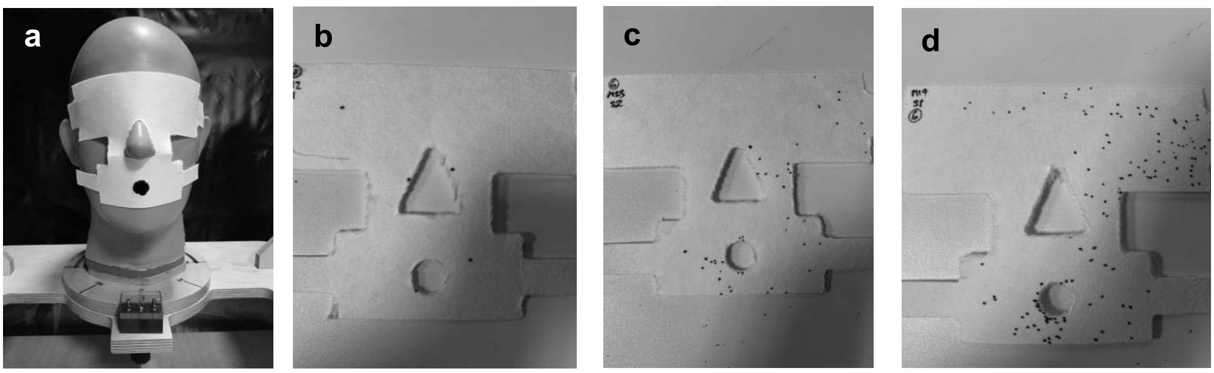


Figure 8 a) Blank sample on manikin head and contaminated samples representing b) low, c) medium and d) high levels of contamination

To aid analysis, each classification was also assigned a numerical score. Undetectable contamination = 0, low = 1, medium = 2 and high = 3.

Although fluorescence was clear to see by eye and to record, it was difficult to photograph, particularly for low levels of contamination. Due to this, areas of the contamination were marked with a black pen before photographing each sample.

2.7 Exploring test methods for resource-limited countries

A Spraytec laser diffraction system (Malvern Panalytical) was used to measure the droplet size distribution in real-time from a number of different spray methods.

Three different spray bottles were chosen based on their immediate availability from the home and laboratory (Figure 9). The aim of these tests was to compare the droplet size distribution from the three different spray bottles, the cough simulator and the airbrush.

Each spray bottle was tested containing water, the airbrush was tested separately containing water and the fluorescein solution and the cough simulator was tested containing fluorescein.

The instrument was positioned 60 cm in front of the spray source and perpendicular to the direction of spray. A minimum of three repeat tests was carried out for each.

Figure 9 Three spray bottles (left to right: A, B and C)

2.8 Smoke visualisation

Initial observations during the early stages of testing suggested that more contamination occurred when the manikin head was turned sideways when wearing a face shield compared to when not wearing one. This prompted an investigation using smoke generation to visualise the air flow patterns and to determine whether wearing a face shield actually increased the flow of aerosol into the breathing zone inside the face shield. With the manikin head turned to the side, smoke tubes (Mine Safety Appliances Company, USA) were used to generate smoke between the cough delivery point and the manikin head. A cough from the cough simulator was timed to coincide with an inhalation from the breathing machine. Immediately following a cough, the path of the smoke was observed, firstly with no face shield on the manikin head, and then with a representative face shield in place.

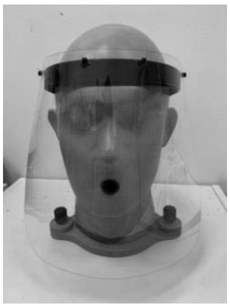
3 RESULTS

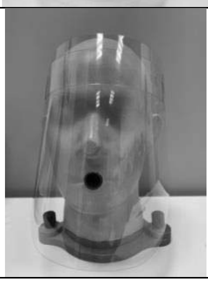
3.1 Dimensions, fit and wear-ability

Table B1 in Appendix B summarises the dimensions of each face shield tested, together with comments on construction.

Table 1 summarises views on wear-ability of the face shields as determined by the project team during challenge testing.

Table 1 Comfort and wear-ability of each face shield

Face Shield	Image	Comfort and wear-ability
PH20194/02		• Comes ready assembled • Easy to put on and fasten • Not adjustable for different head sizes • Comfortable to wear • Stays in place well • Snags on the chest slightly when looking down when worn by person with smaller head.
PH20194/15		• Requires assembly before use • Fairly easy to put together as the visor just fits over 4 plastic pegs. • Easy to put on but difficult to fasten • Small adjustments can be made for different head sizes but still loose on a smaller head. • Digs in at the temples so may cause discomfort after long term wear. • Stays in place well • Catches on the shoulders when turning sideways.
PH20194/16		• Comes ready assembled • Easy to put on with no fastenings • Not adjustable for different head sizes • Difficult to wear if you already wear glasses • Comfortable to wear • Stays in place well • Big gap at the top of the head and the bottom when the head tilts.
PH20194/17		• Comes ready assembled • Easy to put on and fasten • Adjustable for different head sizes • Comfortable to wear • Stays in place well

Face Shield	Image	Comfort and wear-ability
PH20194/18		• Comes ready assembled • Easy to put on and fasten • Not adjustable for different head sizes, and a little tight on a larger head • Comfortable to wear • Stays in place well
PH20194/19		• Comes ready assembled • Easy to put on with no fastenings • Not adjustable for different head sizes • Difficult to wear if you already wear glasses • Comfortable to wear • Stays in place well • Good length on small head although on the large head it was very close to the chin almost forming a seal. • Steams up quickly as it is close to the mouth
PH20194/20		• Comes ready assembled • Easy to put on with no fastenings • Not adjustable for different head sizes • Fairly comfortable to wear, although some visors had exposed staples that may scratch the wearer. • Stays in place well • The plastic visor on many was misshapen and asymmetrical, obscuring vision. • Visor felt thin and flimsy
PH20194/21		• Requires assembly before use • Easy to put together • Easy to put on and fasten • Easy to adjustment to fit different size heads • Comfortable to wear • Wobbles around a lot when an individual moves. • Visor felt thin and flimsy
PH20194/22		• Requires assembly before use • Easy to put together • Easy to put on but difficult to fasten • Adjusts to different head sizes • Comfortable to wear • Movement causes it to come undone • Very long and snags on the chest slightly when looking down.
PH20194/23		• Comes ready assembled • Easy to put on and fasten • Not adjustable for different head sizes • It is not clear how it should be worn. If worn on the forehead it squashes the nose and the plastic cuts into the head. If it is at the top of the head it is very unstable and the plastic is close to the mouth. • Very uncomfortable to wear • Not stable when worn and falls off if head tilted back. • Very long and catches on an individuals chest if you look down. (It kept catching on the cradle of the test rig during testing).

3.2 Protection against droplets

3.2.1 Overview

A summary of the average contamination scores in the eyes, nose and mouth areas for each face shield at each manikin head position are presented in Appendix C and D for the small and large manikin heads respectively. The colour coding assists in quickly identifying the relative extent of contamination.

A more detailed evaluation of the data is summarised in the following report sections.

3.2.2 Best and worst performing face shields on the small and large manikin heads

A numerical score was assigned where 3 was the highest level of fluorescent deposition, 2 was medium deposition, 1 was the lowest level deposition and 0 was no detectable deposition.

For the three test regions (eyes, nose, mouth) for each of 7 orientations of the manikin head, the maximum (worst) score for each face shield would be 63.

Based on the average of three replicate tests, from the above scoring system the face shields ranked from the lowest to highest overall contamination scores are shown in Table 2 for the small and large manikin heads.

Table 2 Mean contamination scores for each face shield on the small and large manikin heads

Small head			Large head		
Ranking	Face shield	Mean overall contamination score (/63)	Ranking	Face shield	Mean overall contamination score (/63)
1	PH20194/21	2	1	PH20194/15	8
2	PH20194/17	3	2	PH20194/18	9
3	PH20194/18	4	3	PH20194/17	18
=4	PH20194/20	15	4	PH20194/23	21
	PH20194/15	15	5	PH20194/02	22
	PH20194/23	15	6	PH20194/20	27
=7	PH20194/19	20	7	PH20194/22	28
	PH20194/02	20	8	PH20194/21	29
9	PH20194/22	23	9	PH20194/16	35
10	PH20194/16	27	10	PH20194/19	39

3.2.3 Fluorescence deposition in the mouth region

Table 3 summarises the performance of the face shields by specifically considering fluorescence deposition in the mouth region.

Table 3 Droplet deposition in the mouth region for each face shield

Face shield	Small head					Face shield	Large head				
	Low	**Medium**	**High**	**Cumulative Total* (%)**	**Ranking**		**Low**	**Medium**	**High**	**Cumulative Total* (%)**	**Ranking**
PH20194/21	3	0	0	**3 (14.3)**	1	PH20194/15	7	0	0	**7 (33.3)**	**1**
PH20194/17	4	0	0	**4 (19.0)**	2	PH20194/18	12	0	0	**12 (57.1)**	**2**
PH20194/18	4	0	0	**4 (19.0)**		PH20194/02	8	4	3	**15 (71.4)**	**3**
PH20194/20	10	3	1	**14 (66.7)**	3	PH20194/16	5	5	8	**18 (85.7)**	**4**
PH20194/23	11	3	2	**16 (76.2)**	4	PH20194/17	12	4	2	**18 (85.7)**	
PH20194/19	14	2	1	**17 (81.0)**	5	PH20194/22	4	5	9	**18 (85.7)**	
PH20194/02	10	7	1	**18 (85.7)**	6	PH20194/21	8	4	7	**19 (90.5)**	**5**
PH20194/16	8	6	4	**18 (85.7)**		PH20194/23	12	3	4	**19 (90.5)**	
PH20194/22	7	4	7	**18 (85.7)**		PH20194/19	8	5	7	**20 (95.2)**	**6**
PH20194/15	14	4	1	**19 (90.5)**	7	PH20194/20	11	4	5	**20 (95.2)**	

3.2.4 Breaches associated with different head positions

Table 4 shows the number of times high, medium or low levels contamination occurred in each manikin head position for the small and large manikin heads across all face shields.

Table 4 Number of times high, medium and low levels of contamination were observed in all regions of the sample for all face shields at each position

Head size	Breach	Position							Total[2]
		1 Front straight	2 Front up	3 Front down	4 Left up	5 Left down	6 Right up	7 Right down	
Small	High[1]	0	8	13	3	1	8	1	33
	Medium[1]	0	10	2	16	3	13	7	51
	Low[1]	29	30	25	42	33	33	34	226
	Total[3]	29	74	68	83	42	83	51	430[4]
Large	High[1]	2	29	9	27	3	28	4	102
	Medium[1]	2	8	1	27	9	20	10	77
	Low[1]	37	39	32	27	39	29	42	245
	Total[3]	47	142	61	162	66	153	74	645[4]

[1]Maximum of 90; 10 face shields x 3 sample regions x 3 repeat tests

[2]Total out of 630 (90 x 7) except for [4]

[3]Maximum of 270; 10 face shields x 3 sample regions x 3 repeat tests x 3 possible levels of contamination

[4]Maximum of 1890 (270 x 7)

3.2.5 Smoke visualisation

Without a face shield in place, smoke generated near to the breathing manikin could be seen to pass around both sides of the head, i.e., around the face and the back of the head. More smoke was observed to pass around the back of the head, which may be anticipated as the manikin head is not symmetrical and smoke may have followed the shorter path around the back of the head or dissipated more due to the features on the face. Some of the smoke that passed across the face could be seen to have been "breathed in".

With the face shield in place, the smoke again passed around both sides of the head. However, this time more smoke was drawn across the face of the manikin. Smoke could be seen to be mainly drawn behind the face shield and across the face where it was mostly breathed in. Figure 10 depicts the airflow patterns with and without a face shield worn, while Figure 11 shows the smoke movement under a face shield.

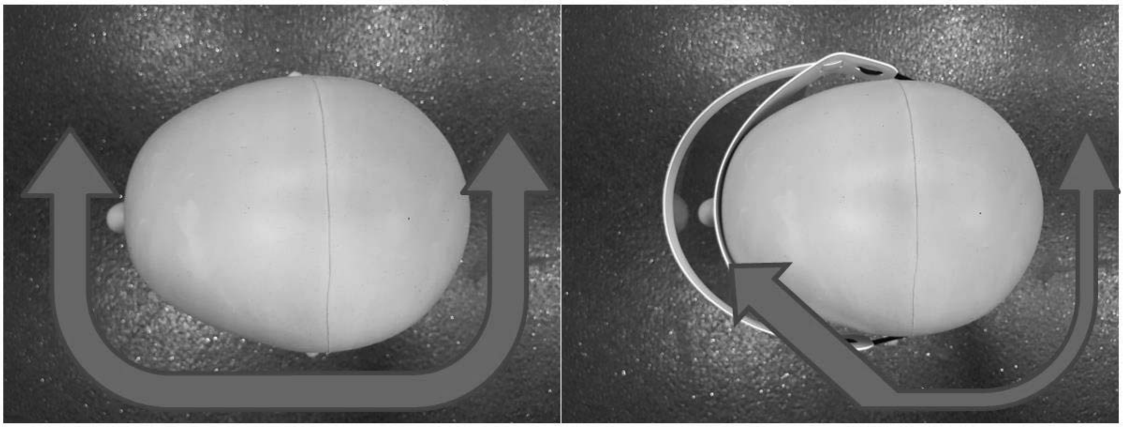


Figure 10 Air flow patterns around manikin head with and without face shield as observed from smoke generation

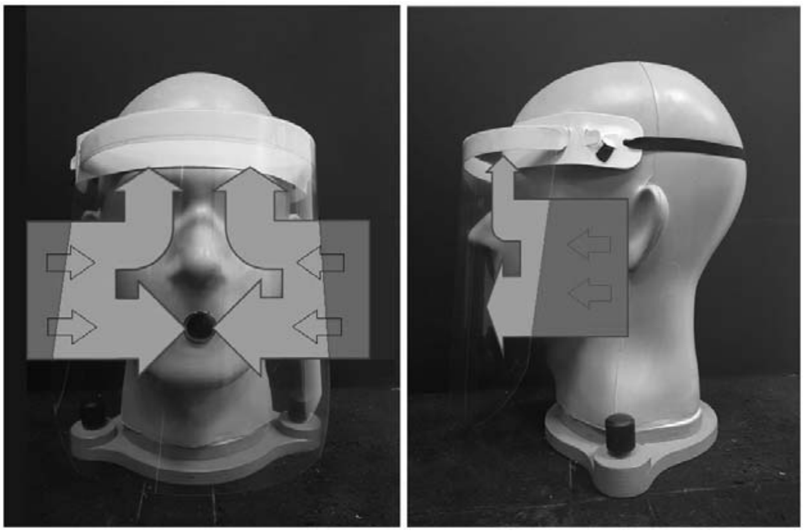


Figure 11 Air flow patterns around manikin head under face shield as observed from smoke generation. Blue indicates smoke entering and grey where it exits

3.3 Test methods for resource-limited countries

The Spraytec reports the droplet size distribution results as a percentage of the total volume of the spray at each particle size. A small number of larger droplets can account for a large percentage of the spray volume. The instrument requires a large obscuration of the laser light in order to take a reliable measurement and unfortunately this requirement could not be met for the cough simulator and its size distribution could not be measured. The trigger of spray bottle B failed to reliably deliver spray from the bottle and therefore data was not collected for this option either. Figure 12 shows the droplet size distribution produced by the airbrush containing water and fluorescein and for spray bottles A and C containing water.

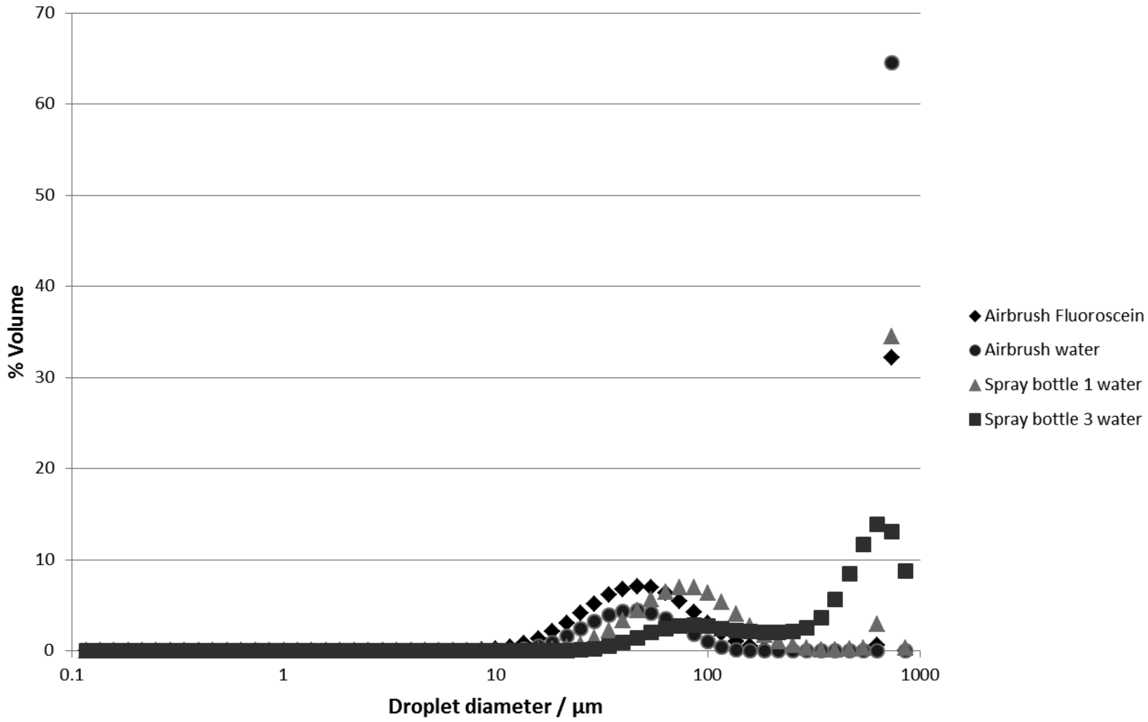


Figure 12 Droplet size distributions as a percentage volume of the total spray for the airbrush containing fluorescein and containing water and spray bottles A and C containing water. The x-axis follows is a logarithmic scale.

4 DISCUSSION

4.1 Developing the methodology

Phase 1 of this project was to develop test methodology by which face shields could be tested for their protectiveness against a droplet challenge to mimic a human cough. A test rig was constructed based on the design described in European Standard BS EN166 and capable of accommodating both large and small manikin heads, therefore representative of head sizes and shapes in the majority the adult population across the World. It differed from the BS EN166 test rig in that the manikin heads deployed for this project were capable of breathing, by connection to a breathing simulator calibrated to mimic human inspiration. This meant that exposing face shields to a cough challenge with a fluorescent marker could be conducted under the worst-case scenario of a cough occurring at the same time as the face shield wearer breathing in.

A cough simulator was designed and built based on an in-house adaptation of a previously published design principle and by following the previous design it was shown from first principles to accurately mimic a human cough. This combination of apparatus was used to test a range of face shields.

4.2 Face shield models and testing

In Phase 2 of the project, ten face shield models representative of those entering the global PPE supply chain for use by both healthcare professionals and members of the public, were sourced and tested. This included face shields from the UK, from WHO, from research partners in Brazil and Nigeria, and from Tanzania.

As well as recording the dimensions of each face shield, general comfort and wear-ability observations were also made. For example, some face shields were difficult to fasten and wear or the plastic from which the visor was made was flimsy or was too close to the nose. Further feedback from the user questionnaire conducted in Brazil and Nigeria in Phase 3 will place these data in further context.

The face shields were mounted on the manikin head according to manufacturer instructions, where available. The results of the tests reported here would be invalidated if the face shield were to be worn differently. The authors have observed face shields worn incorrectly in the field, one adaptation being that the face shield is worn with the headband higher on the forehead and lower on the back of the head increasing the gap between the mouth and face shield.

The tests demonstrated the range of protectiveness afforded by different face shield designs. It was not within the scope of this project to determine the significance of the breaches, i.e., whether the level of breaches made a face shield ‘safe’ or ‘unsafe’, but to highlight that in some circumstances some are more protective than others. For example, by testing in different orientations it was shown that face shields which were more open at the head band led to breaches when the manikin head was tilted forward, while face shields with a shorter visor led to breaches when the manikin head was tilted back. There were more breaches, or breaches at a higher concentration, on a large manikin head compared to a small head, presumably because of less coverage at the periphery of the face.

4.3 Results

4.3.1 Comparing face shield performance on the small and large head

The face shields were ranked from best to worst performing based on the mean overall contamination score (out of 63) for each face shield. On the small head, the best performing face shields were PH20194/21, PH20194/17 and PH20194/18, scoring 2, 3 and 4 respectively. The best performing face shields on the large manikin head were PH20194/15 and PH20194/18 scoring 8 and 9 respectively.

The worst performing face shields were PH20194/16 (scoring 27) on the small head, and PH20194/19 (scoring 39) on the large head.

The results demonstrate the protection afforded by each face shield could vary depending on the head size. For example:

- Face shield PH20194/17 (Tanzanian recycled material) - When tested on the small head, the results demonstrated that it was one of the more effective visors with a low average score of 3. In comparison, when tested on the large head, the average score was 18 with heavy contamination on the mouth area in position 2 and medium contamination found in the eye and mouth areas in position 4.
- Face shield PH20194/21 (Brazilian with white head band) - This visor was demonstrated to be the most effective when tested on the small head with an average score of 2. However, when tested on the large head, the average score was 29 with high levels of contamination found when the head was in positions 2 (eyes, nose, mouth); 4 (eyes, nose, mouth); 6 (eyes, mouth); and 7 (nose and mouth).

4.3.2 Fluorescence deposition in the mouth region

As the face shields aim to provide some protection against a respiratory virus, arguably the level of protection afforded to the mouth region is paramount. The tests presented the worst-case scenario of a cough coinciding with the manikin breathing in.

It is also important to reiterate that the standard testing used by notified bodies to assess the protection afforded by face shields only considers protection to the eyes and not the nose or mouth.

Face shields PH20194/17, PH20194/18 and PH20194/21 provided the best protection on the small head and PH20194/15 and PH20194/18 on the large head. However, face shield PH20194/15 had the greatest number of observable deposits in the mouth region on the small head, albeit mostly in the low category.

4.3.3 Breaches associated with different head positions

Across all 10 face shields, on the small manikin head, position 4 (left looking up) and position 6 (right looking up) gave the highest breach score (83 out of a maximum of 270) although mostly as a consequence of low level breaches, while position 3 (front looking down) resulted in the largest number of high level breaches (13 out of 90).

- In position 1 (front face on) all face shields were reasonably protective;
- In position 2 (front looking up) three of the face shields (PH20194/02, PH20194/16, PH20194/22) had on average a high level of breach at the mouth region;
- In position 3 (front looking down) face shield PH20194/16 had on average a high level of breach at the mouth, nose and eye region, while face shield PH20194/19 had a high-level breach in the eye region;
- In position 4 (left looking up) only face shield PH20194/22 had on average a high level of breach at the mouth region;
- In position 5 (left looking down) all face shields were reasonably protective;
- In position 6 (right looking up) face shield PH20194/16 had on average a high level of breach at the eye region), face shield PH20194/19 had a high level breach in the eye and mouth region, and face shield PH20194/23 had a high level breach in the mouth region;
- In position 7 (right looking down) only face shield PH20194/22 had on average a high level of breach at the mouth region.

On the large manikin, head position 4 (left looking up) again gave the highest breach score (162 out of a maximum of 270), while positions 2 (front looking up) and 6 (right looking up) also gave high breach scores (142 and 153 out of 270 respectively). All three of these positions resulted in large numbers of high level breaches: 29 for position 2; 27 for position 4; and 28 for position 6 (each out of 90).

- In position 1 (front face on) only face shield PH20194/19 had on average a high level of breach at the eye region;
- In position 2 (front looking up) three of the face shields (PH20194/20, PH20194/21, PH20194/22) had on average a high level of breach at all three regions, face shield PH20194/19 had a high level breach in the eye and mouth region, face shields PH20194/02 and PH20194/17 each had a high level breach in the mouth region;

- In position 3 (front looking down) face shield PH20194/16 had on average a high level of breach at the nose and eye region, while face shield PH20194/19 had a high level breach in the eye region;
- In position 4 (left looking up) face shields PH20194/16, PH20194/19, PH20194/20 and PH20194/21 had on average a high level of breach at all three regions, face shield PH20194/23 had a high level breach in both the eye and mouth region, face shields PH20194/17 and PH20194/22 had high level breaches in and mouth region, and face shield PH20194/2 had a high level breach in the eye region;
- In position 5 (left looking down) only face shield PH20194/22 had on average a high level of breach at the mouth region;
- In position 6 (right looking up) face shields PH20194/02, PH20194/16, PH20194/19, and PH20194/23 had on average a high level of breach at all three regions, face shield PH20194/22 had high level breaches in both the eye and mouth region, face shield PH20194/21 had a high level breach in and mouth region;
- In position 7 (right looking down) face shields PH20194/16 and PH20194/19 had on average high level of breaches at the mouth region.

The results showed that breaches were greater in number and at a higher level of droplet contamination with face shields on the large head, presumably as a consequence of them wrapping round the face less.

The tendency toward breaches occurring with the manikin facing sideways on to the cough prompted an investigation of the airflow patterns around the manikin head with and without a face shield in place. This was done using smoke generation. While this does not necessarily correspond to the flow of all droplets in air, it will mimic the passage of finer droplets. It was observed that more smoke passed behind the head than across the face without a face shield in place, but some smoke could be seen to be inhaled. However, with a face shield in place more smoke was inhaled. Presumably this was because the blunt side of the face shield created a stagnation point leading to greater build-up of smoke. As this entered the breathing zone inside the face shield it is likely the airflow velocity was increased due to the restricted volume leading to a greater amount of smoke being breathed in. This may account for the greater tendency for breaches in this position.

Trends towards contamination associated with face shield shape, as determined from observations and smoke tests, were as follows:

- Face shield PH20194/18, with the visor made from more sturdy plastic and greater length (dimension 6 in Figure 1) and better wrap around, generally performed well.
- Face shields that were wider at the base when worn, i.e., the visor material flared out (PH20194/02, PH20194/16, PH20194/19, PH20194/20,

PH20194/21, PH20194/23) generally gave rise to greater contamination at the sides and looking up.

- Face shields PH20194/2, PH20194/16, PH20194/17, PH20194/19, PH20194/20, PH20194/21 gave rise to greater contamination from the front and looking up, mostly around the mouth region although PH20194/20, PH20194/21 all three regions, probably because of the shorter visor length (dimension 6 in Figure 1).
- Face shields with foam head bands (PH20194/02, PH20194/17, PH20194/18) afforded greater protection from the top (manikin looking down). PH20194/16 and PH20194/19 were open at the top and also sat lower on the forehead and these gave rise to greater contamination when looking down. Even though others were also open at the top they appeared to provide greater protection, which may have been due to other influences on shape and wearing position on the face.
- Face shield PH20194/19 performed much better on the small head than the large head although still showed heavy contamination in the eye region (front and looking down) and right looking up because of the cut-away shaping of the rigid visor material. Smoke tests showed the air current was pulled around the mouth and exited at the top.
- Face shield PH20194/22 generally performed poorly due to the flimsy plastic material from which it was made.

4.3.4 Resource limited countries

Consideration was given to how to adapt the methods developed for this work for use in resource-limited countries.

The first option would be to substitute the cough simulator for another droplet source. The airbrush could be used alone. Although it is suspected that more liquid would be delivered in a burst from the airbrush compared with a human cough, it would deliver a reliable source of spray and a repeatable droplet size distribution. Other options for producing droplets were considered.

Spray bottle A produced consistent spray distributions on the first trigger each time. The droplet size distribution was slightly larger than that for the airbrush. Recycled spray bottles such as spray bottle A tested here could be an appropriate substitute for the cough simulator when testing face shields.

It was not possible to measure the droplet size distribution of spray bottle B, as the trigger sometimes failed to deliver any spray, and when it did it was more of a stream than a spray.

Spray bottle C did not produce a consistent spray and sometimes needed an initial trigger to ‘prime’ the bottle with the second spray being more consistent and containing more of the smaller droplets. The droplet size distribution was bimodal, with the second peak much larger than that for the airbrush or spray bottle A.

Another adaptation of the method could be to replace the breathing machine with a non-breathing manikin or to attach a simple pump to the manikin head to constantly 'inhale'.

It would be possible to replace the fluorescent liquid used in this study with an alternative such as a visible dye. This would also negate the need for a UV light source. The droplet size distribution analysis for the airbrush used with water and with fluorescein showed similar results.

5 CONCLUSIONS

A method was developed and implemented to assess the level of protection afforded by different face shields against droplets from a simulated human cough.

The results demonstrate the protection afforded by each face shield could vary depending on the head size. Breaches were greater in number and at a higher level of droplet contamination with face shields on the large head.

On the small head, the best performing face shields were PH20194/21, PH20194/17 and PH20194/18. The best performing face shields on the large manikin head were PH20194/15 and PH20194/18.

The worst performing face shields were PH20194/16 on the small head and PH20194/19 on the large head.

None of the face shields tested totally eliminated exposure, and there were differences in the level of protection afforded by each. The orientation of the head influenced the level of protection and in some instances this could be associated with design features. For example, breaches occurred where face shields were more open at the bottom if the head was tilted back.

Across all 10 face shields, on the small manikin head, position 4 (left looking up) and position 6 (right looking up) gave the highest breach score although mostly as a consequence of low level breaches, while position 3 (front looking down) resulted in the largest number of high level breaches.

On the large manikin, head position 4 (left looking up) again gave the highest breach score, while positions 2 (front looking up) and 6 (right looking up) also gave high breach scores. All three of these positions resulted in large numbers of high level breaches.

The methods developed here could be adapted for use in resource-limited countries by using recycled spray bottles to produce visible dye droplets and using a pump to simulate inhalation.

6 REFERENCES

British Standards Institution (BSI) BS EN 166:2002 Personal eye-protection — Specifications

Lindsley WG, Blachere FM, Thewlis RE, Vishnu A, Davis KA, et al. 2010. Measurements of Airborne Influenza Virus in Aerosol Particles from Human Coughs. PLoS ONE 5(11): e15100. doi:10.1371/journal.pone.0015100

Lindsley WG, Reynolds JS, Szalajda JV, Noti JD & Beezhold DH. 2013. A Cough Aerosol Simulator for the Study of Disease Transmission by Human Cough-Generated Aerosols, Aerosol Science and Technology, 47:8, 937-944. DOI: 10.1080/02786826.2013.803019

APPENDIX A PHOTOGRAPHS OF FACE SHIELDS ON THE SMALL MANIKIN HEAD

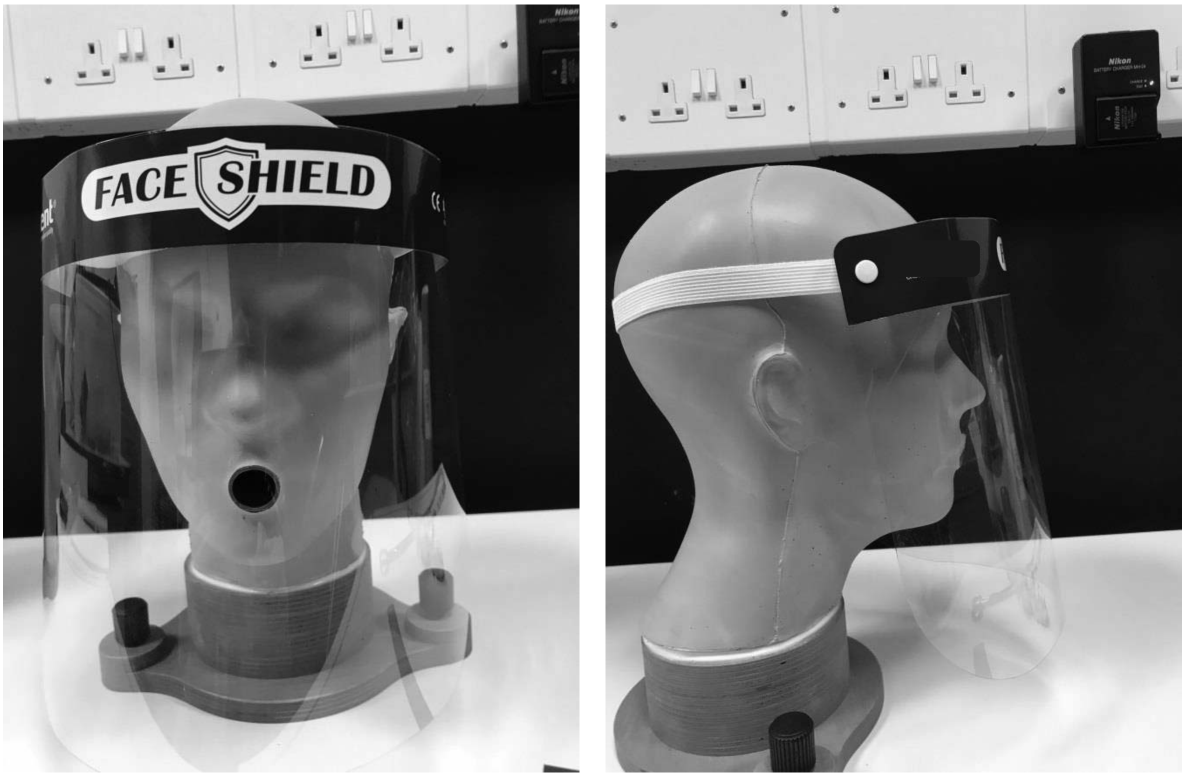


Figure A1 Photographs of face shield PH20194/02 on the small manikin head

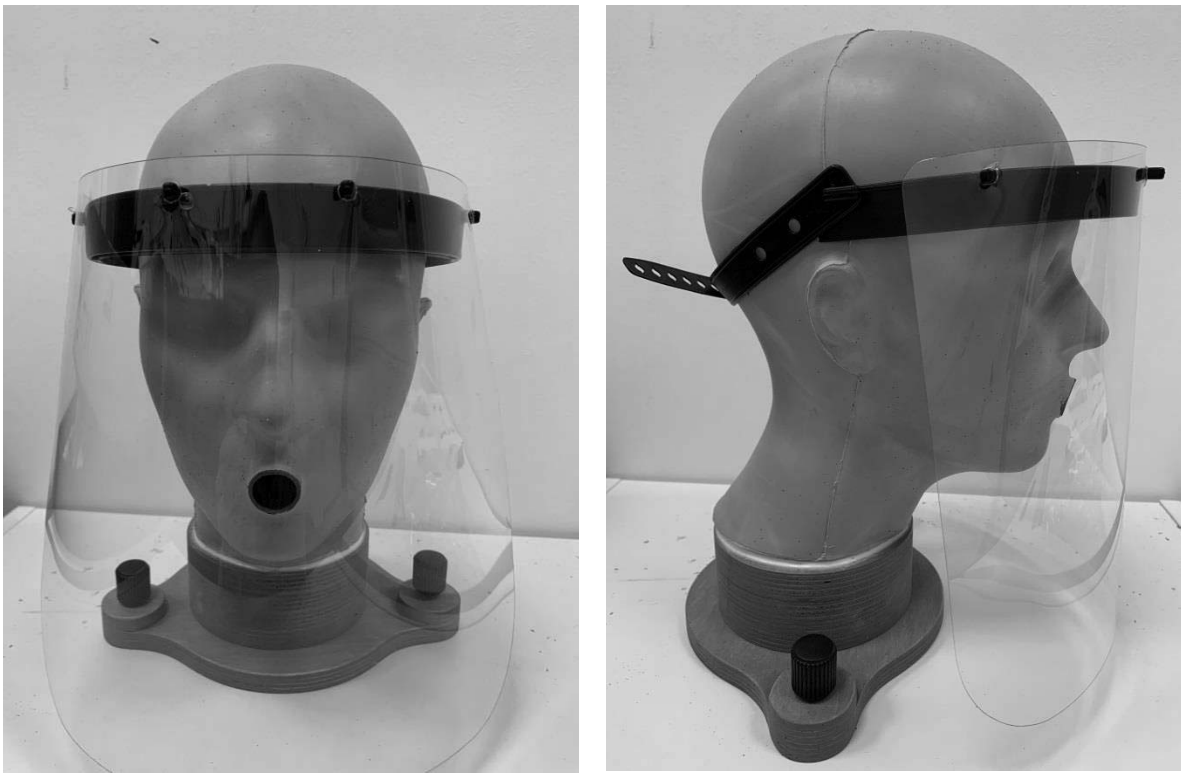


Figure A2 Photographs of face shield PH20194/15 on the small manikin head

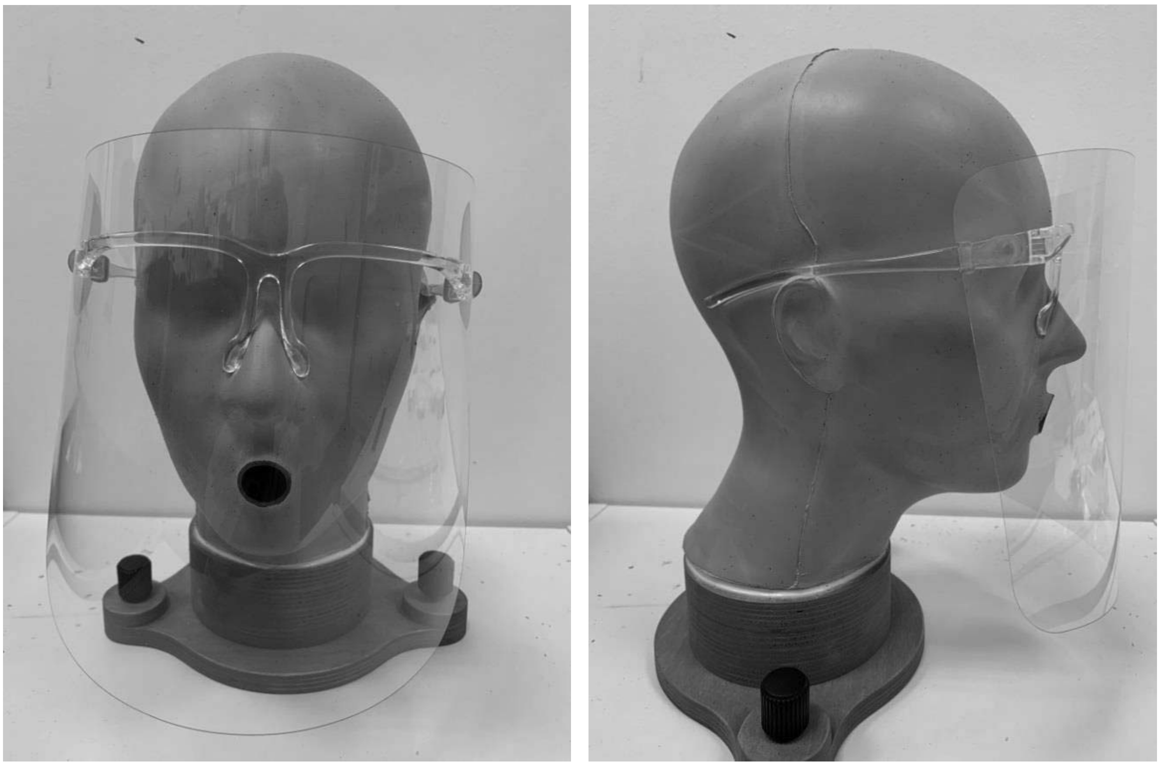


Figure A3 Photographs of face shield PH20194/16 on the small manikin head

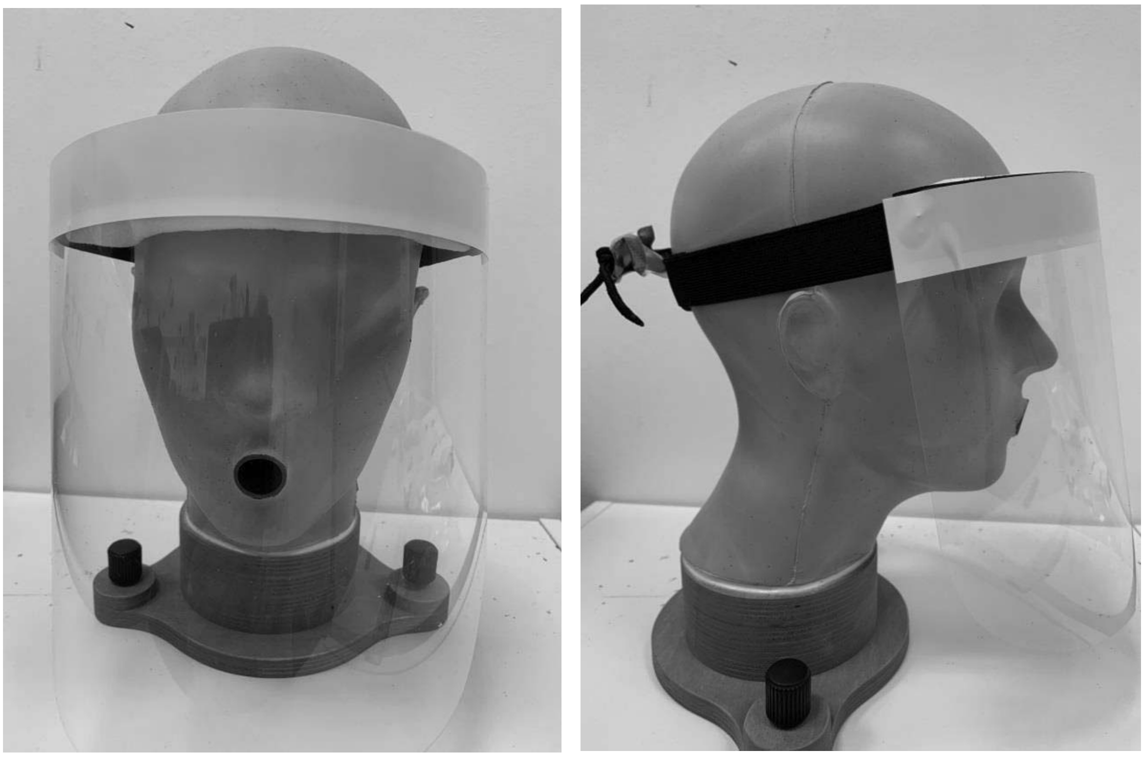


Figure A4 Photographs of face shield PH20194/17 on the small manikin head

Figure A5 Photographs of face shield PH20194/18 on the small manikin head

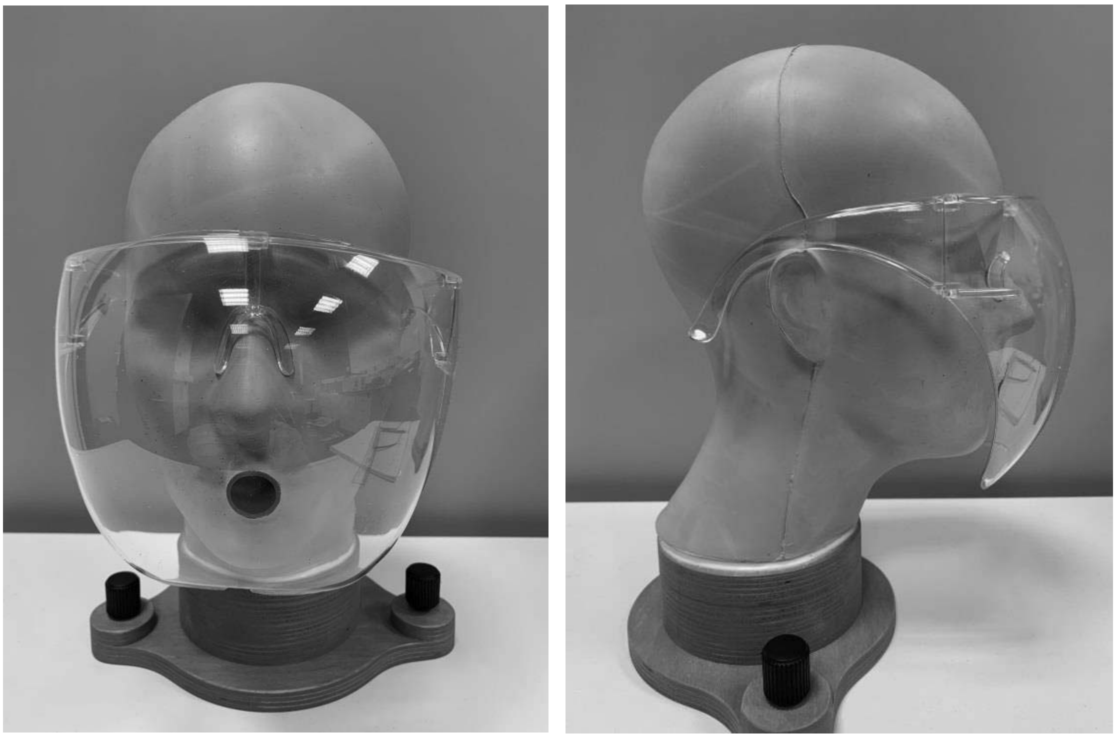


Figure A6 Photographs of face shield PH20194/19 on the small manikin head

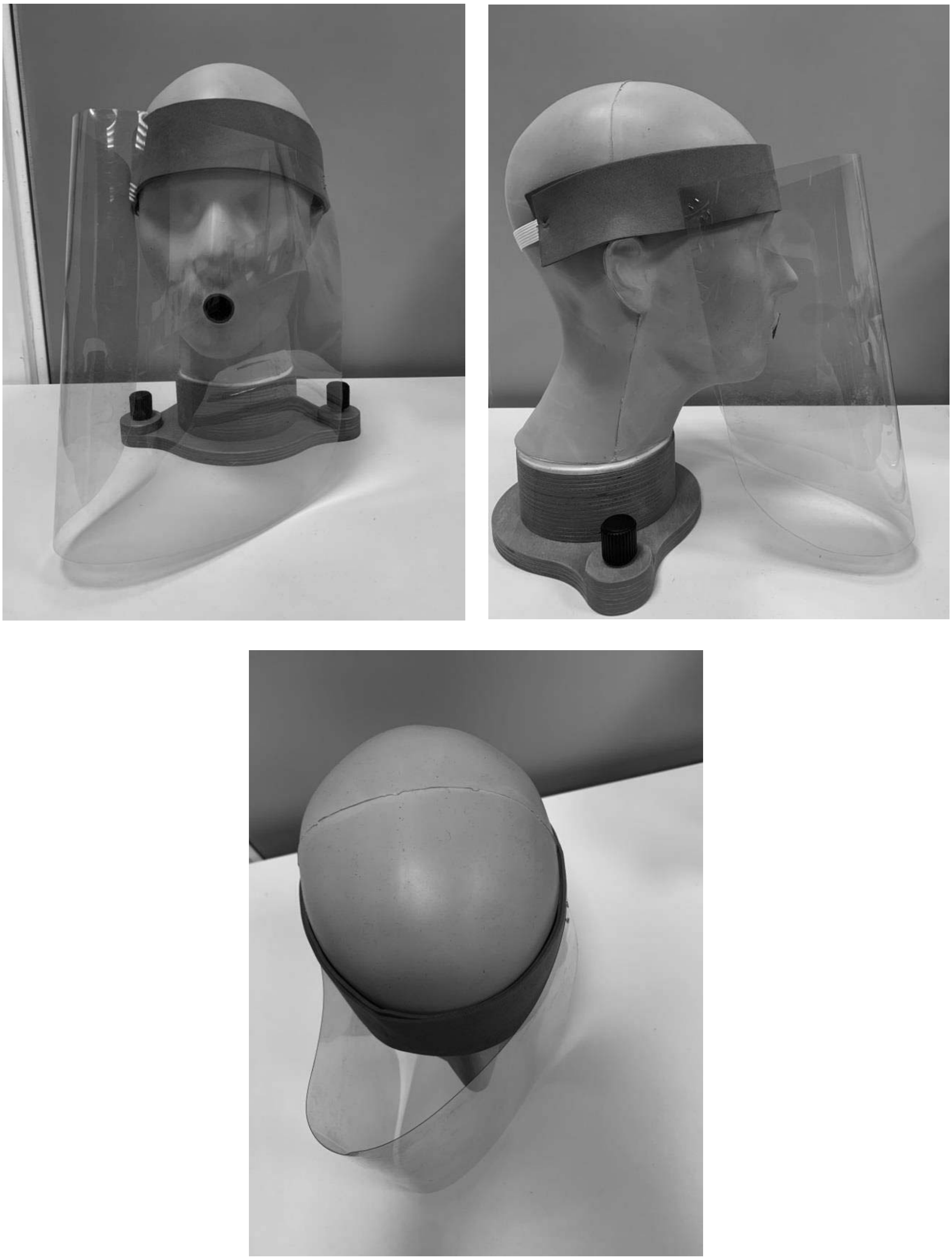


Figure A7 Photographs of face shield PH20194/20 on the small manikin head

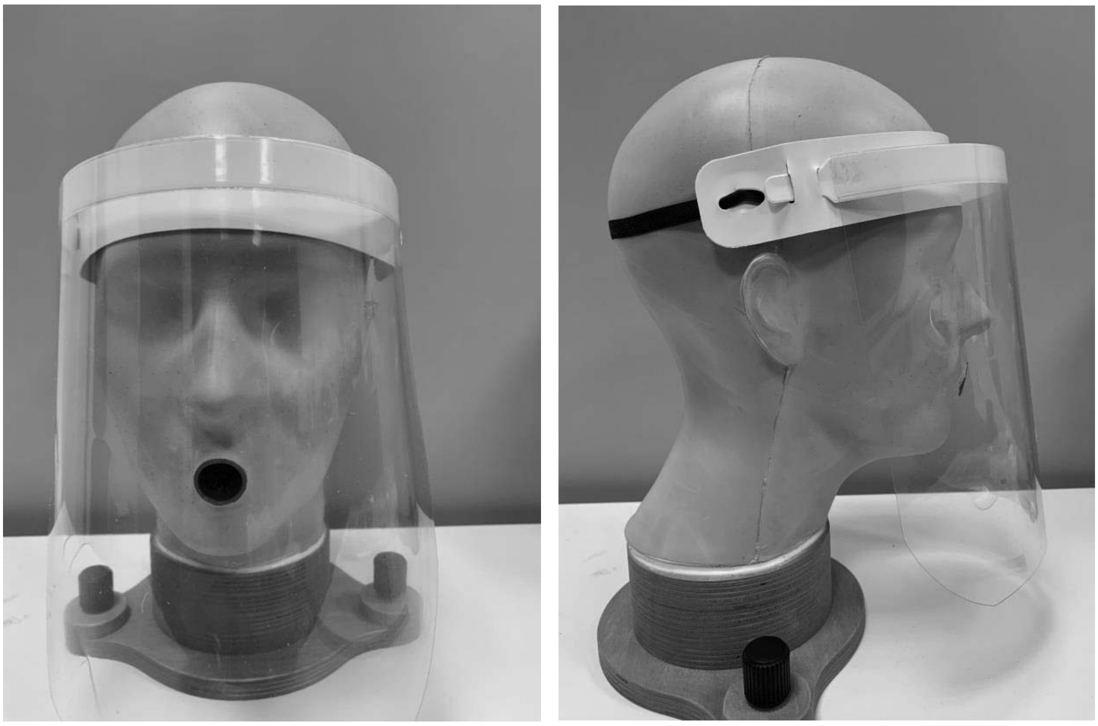


Figure A8 Photographs of face shield PH20194/21 on the small manikin head

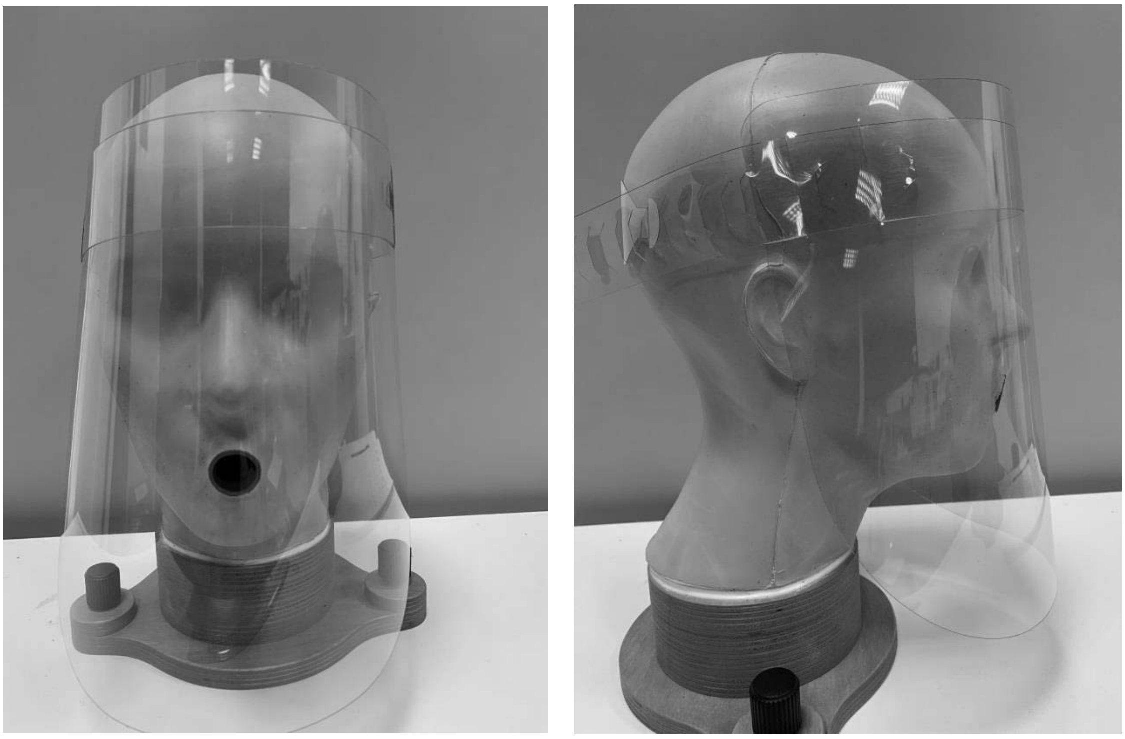


Figure A9 Photographs of face shield PH20194/22 on the small manikin head

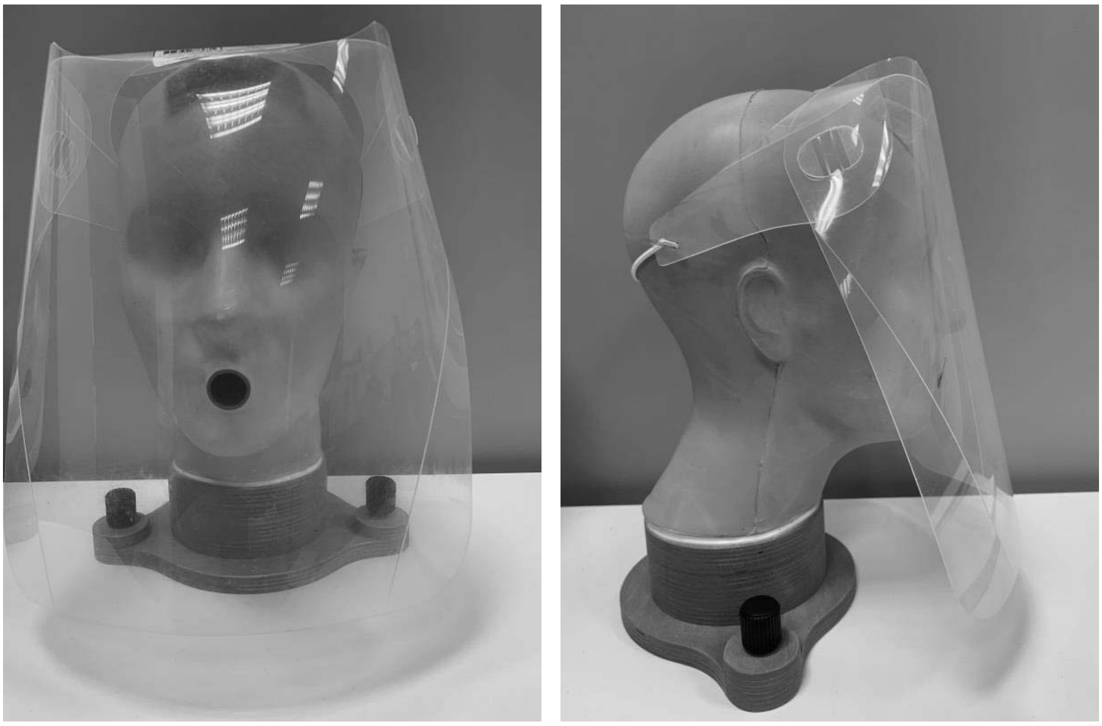


Figure A10 Photographs of face shield PH20194/23 on the small manikin head

APPENDIX B FACE SHIELD DIMENSIONS

Table B1 Dimensions of each face shield tested and comments on construction

Face Shield	Dimensions (see section 2.2.1 for descriptions of measurements 1-6) / mm							Comments
	1	2, 3	4	5	6	Face shield to ear (large)	Face shield to ear (small)	
PH20194/02	15	29, 35	311	182	221	31	35	Comes in one piece with visor attached to foam headband
PH20194/15	19	N/A	290	202	230	46	34	Hard plastic headband to which visor attaches by lugs
PH20194/16	N/A	N/A	250	155	195	80	60	Shaped nose piece and arms like spectacles to which visor attaches by lugs
PH20194/17	30	30,35	297	180	210	44	43	Comes in one piece with visor attached to foam headband
PH20194/18	32	32,30	348	208	240	17	0	Comes in one piece with visor attached to foam headband
PH20194/19	N/A	N/A	240	N/A	145	82	72	Like an extended goggle
PH20194/20	44	44,4	310	215	240	36	41	2 thin pieces of foam badly stapled together with an 11mm elastic strap
PH20194/21	35	N/A	262	183	218	47	45	Visor attaches to thin plastic headband secured on head by 9 mm elastic strap
PH20194/22	38	N/A	305	185	240	22	4	plastic strip fed through top of visor touches nose on large manikin, too loose on small manikin, can't keep strap hooked in
PH20194/23	50	N/A	290	N/A	260	60	58	single piece goes over front of head good idea but touches nose on both manikins and sticks out too much at bottom

APPENDIX C AVERAGE CONTAMINATION SCORES IN THE EYE, NOSE AND MOUTH AREAS FOR EACH FACE SHIELD AT EACH MANIKIN HEAD POSITION FOR THE SMALL HEAD

Table C1 Average contamination scores in the eye, nose and mouth areas for each face shield at small manikin head position 1 (colour coding: Grey=0 and 0 < Green < 1 ≤ Yellow < 2 ≤ Red)

Head orientation	Face shield test results mean of 3 replicates				
					
	PH20194/02	PH20194/15	PH20194/16	PH20194/17	PH20194/18
	Eyes: 0.33	Eyes: 0	Eyes: 0	Eyes: 0.33	Eyes: 0.33
	Nose: 0.33	Nose: 0.33	Nose: 0.33	Nose: 0	Nose: 0
	Mouth: 1.0	Mouth: 0.33	Mouth: 0.33	Mouth: 0.33	Mouth: 0
Position 1: Front and face on					
	PH20194/19	PH20194/20	PH20194/21	PH20194/22	PH20194/23
	Eyes: 0.67	Eyes: 0.33	Eyes: 0	Eyes: 0	Eyes: 0
	Nose: 0	Nose: 0	Nose: 0	Nose: 0.33	Nose: 0.33
	Mouth: 0.33	Mouth: 0.67	Mouth: 0.33	Mouth: 0.33	Mouth: 0.33

Table C2 Average contamination scores in the eye, nose and mouth areas for each face shield at small manikin head position 2 (colour coding: Grey=0 and 0 < Green < 1 ≤ Yellow < 2 ≤ Red)

Head orientation	**Face shield test results mean of 3 replicates**				
					
	PH20194/02	PH20194/15	PH20194/16	PH20194/17	PH20194/18
	Eyes: 1.33	Eyes: 0.33	Eyes: 1.67	Eyes: 0	Eyes: 0
	Nose: 1.33	Nose: 0.33	Nose: 0.67	Nose: 0	Nose: 0.33
	Mouth: 2.33	Mouth: 0.67	Mouth: 2.0	Mouth: 0.33	Mouth: 0.33
Position 2: Front and looking up					
	PH20194/19	PH20194/20	PH20194/21	PH20194/22	PH20194/23
	Eyes: 1.33	Eyes: 1.0	Eyes: 0	Eyes: 1.67	Eyes: 0.33
	Nose: 0.67	Nose: 0.67	Nose: 0.33	Nose: 1.33	Nose: 0
	Mouth: 1.33	Mouth: 1.67	Mouth: 0	Mouth: 2.67	Mouth: 0

Table C3 Average contamination scores in the eye, nose and mouth areas for each face shield at small manikin head position 3 (colour coding: Grey=0 and 0 < Green < 1 ≤ Yellow < 2 ≤ Red)

Head orientation	**Face shield test results mean of 3 replicates**				
 Position 3: Front and looking down					
	PH20194/02	PH20194/15	PH20194/16	PH20194/17	PH20194/18
	Eyes: 0.67	Eyes: 1.0	Eyes: 3.0	Eyes: 0.33	Eyes: 0.33
	Nose: 0.33	Nose: 0	Nose: 3.0	Nose: 0	Nose: 0
	Mouth: 0	Mouth: 0.67	Mouth: 3.0	Mouth: 0	Mouth: 0
					
	PH20194/19	PH20194/20	PH20194/21	PH20194/22	PH20194/23
	Eyes: 3.0	Eyes: 1.67	Eyes: 0	Eyes: 1.33	Eyes: 0.33
	Nose: 0.67	Nose: 0.33	Nose: 0.33	Nose: 0.67	Nose: 0
	Mouth: 0.33	Mouth: 0.67	Mouth: 0	Mouth: 0.67	Mouth: 0.33

Table C4 Average contamination scores in the eye, nose and mouth areas for each face shield at small manikin head position 4 (colour coding: Grey=0 and 0 < Green < 1 ≤ Yellow < 2 ≤ Red)

Head orientation	Face shield test results mean of 3 replicates				
					
	PH20194/02	PH20194/15	PH20194/16	PH20194/17	PH20194/18
	Eyes: 1.67	Eyes: 1.67	Eyes: 1.67	Eyes: 0	Eyes: 0
	Nose: 1.33	Nose: 0.67	Nose: 1.33	Nose: 0.33	Nose: 0.33
	Mouth: 1.67	Mouth: 1.33	Mouth: 1.67	Mouth: 0	Mouth: 0.67
Position 4: Left and looking up					
	PH20194/19	PH20194/20	PH20194/21	PH20194/22	PH20194/23
	Eyes: 1.0	Eyes: 1.0	Eyes: 0	Eyes: 1.0	Eyes: 1.67
	Nose: 0.67	Nose: 0.67	Nose: 0	Nose: 0.67	Nose: 1.0
	Mouth: 1.0	Mouth: 1.0	Mouth: 0	Mouth: 2.33	Mouth: 1.33

Table C5 Average contamination scores in the eye, nose and mouth areas for each face shield at small manikin head position 5 (colour coding: Grey=0 and 0 < Green < 1 ≤ Yellow < 2 ≤ Red)

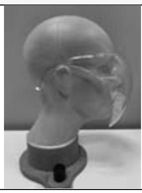
Head orientation	**Face shield test results mean of 3 replicates**				
 Position 5: Left and looking down					
	PH20194/02	PH20194/15	PH20194/16	PH20194/17	PH20194/18
	Eyes: 0.33	Eyes: 0.33	Eyes: 0.33	Eyes: 0.33	Eyes: 0
	Nose: 0.33	Nose: 0	Nose: 0	Nose: 0	Nose: 0.67
	Mouth: 1.33	Mouth: 1.00	Mouth: 0.67	Mouth: 0.33	Mouth: 0
					
	PH20194/19	PH20194/20	PH20194/21	PH20194/22	PH20194/23
	Eyes: 0.33	Eyes: 0.67	Eyes: 0	Eyes: 0.67	Eyes: 0
	Nose: 0.33	Nose: 0	Nose: 0.67	Nose: 1.0	Nose: 0
	Mouth: 1.0	Mouth: 1.0	Mouth: 0	Mouth: 1.33	Mouth: 1.0

Table C6 Average contamination scores in the eye, nose and mouth areas for each face shield at small manikin head position 6 (colour coding: Grey=0 and 0 < Green < 1 ≤ Yellow < 2 ≤ Red)

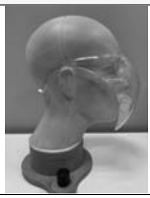
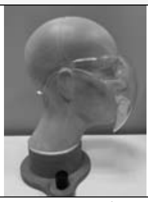
Head orientation	**Face shield test results mean of 3 replicates**				
					
	PH20194/02	PH20194/15	PH20194/16	PH20194/17	PH20194/18
	Eyes: 1.33	Eyes: 1.33	Eyes: 2.33	Eyes: 0	Eyes: 0
	Nose: 0.33	Nose: 1.0	Nose: 1.33	Nose: 0	Nose: 0.33
	Mouth: 1.33	Mouth: 1.67	Mouth: 1.67	Mouth: 0.33	Mouth: 0
Position 6: Right and looking up					
	PH20194/19	PH20194/20	PH20194/21	PH20194/22	PH20194/23
	Eyes: 2.33	Eyes: 0.33	Eyes: 0	Eyes: 1.0	Eyes: 1.33
	Nose: 1.0	Nose: 0.33	Nose: 0	Nose: 0.67	Nose: 1.0
	Mouth: 2.0	Mouth: 0.67	Mouth: 0	Mouth: 1.67	Mouth: 2.33

Table C7 Average contamination scores in the eye, nose and mouth areas for each face shield at small manikin head position 7 (colour coding: Grey=0 and 0 < Green < 1 ≤ Yellow < 2 ≤ Red)

Head orientation	**Face shield test results mean of 3 replicates**				
					
	PH20194/02	PH20194/15	PH20194/16	PH20194/17	PH20194/18
	Eyes: 1.0	Eyes: 0.33	Eyes: 0.33	Eyes: 0.33	Eyes: 0.33
	Nose: 0	Nose: 0.33	Nose: 0.67	Nose: 0.33	Nose: 0
	Mouth: 1.33	Mouth: 1.33	Mouth: 1.33	Mouth: 0	Mouth: 0.33
Position 7: Right and looking down					
	PH20194/19	PH20194/20	PH20194/21	PH20194/22	PH20194/23
	Eyes: 0.33	Eyes: 0.67	Eyes: 0	Eyes: 0.67	Eyes: 0.67
	Nose: 0.33	Nose: 0.33	Nose: 0	Nose: 0.33	Nose: 0.33
	Mouth: 1.0	Mouth: 0.67	Mouth: 0	Mouth: 2.0	Mouth: 1.67

APPENDIX D AVERAGE CONTAMINATION SCORES IN THE EYE, NOSE AND MOUTH AREAS FOR EACH FACE SHIELD AT EACH MANIKIN HEAD POSITION FOR THE LARGE HEAD

Table D1 Average contamination scores in the eye, nose and mouth areas for each face shield at large manikin head position 1 (colour coding: Grey=0 and 0 < Green < 1 ≤ Yellow < 2 ≤ Red)

Head orientation	**Face shield test results mean of 3 replicates**				
 Position 1: Front and face on					
	PH20194/02	PH20194/15	PH20194/16	PH20194/17	PH20194/18
	Eyes: 0.33	Eyes: 0.67	Eyes: 1.0	Eyes: 0.33	Eyes: 0.33
	Nose: 0	Nose: 0.33	Nose: 0.33	Nose: 0.67	Nose: 0
	Mouth: 0.33	Mouth: 0.67	Mouth: 0.33	Mouth: 0.33	Mouth: 0.33
					
	PH20194/19	PH20194/20	PH20194/21	PH20194/22	PH20194/23
	Eyes: 2.67	Eyes: 0	Eyes: 0.33	Eyes: 0.67	Eyes: 0.33
	Nose: 1.0	Nose: 0.33	Nose: 0	Nose: 0	Nose: 0
	Mouth: 0.67	Mouth: 1.33	Mouth: 0.67	Mouth: 0.67	Mouth: 0.67

Table D2 Average contamination scores in the eye, nose and mouth areas for each face shield at large manikin head position 2 (colour coding: Grey=0 and 0 < Green < 1 ≤ Yellow < 2 ≤ Red)

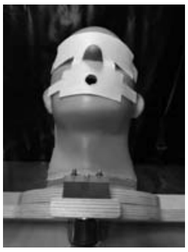
Head orientation	**Face shield test results mean of 3 replicates**				
 Position 2: Front and looking up					
	PH20194/02	PH20194/15	PH20194/16	PH20194/17	PH20194/18
	Eyes: 1.0	Eyes: 0.67	Eyes: 1.0	Eyes: 1.0	Eyes: 0.67
	Nose: 0.67	Nose: 0.33	Nose: 0.67	Nose: 1.0	Nose: 0.67
	Mouth: 2.33	Mouth: 0.67	Mouth: 1.33	Mouth: 2.67	Mouth: 1.0
					
	PH20194/19	PH20194/20	PH20194/21	PH20194/22	PH20194/23
	Eyes: 2.67	Eyes: 3.0	Eyes: 2.0	Eyes: 2.33	Eyes: 0
	Nose: 1.0	Nose: 3.0	Nose: 2.33	Nose: 3.0	Nose: 0.33
	Mouth: 2.33	Mouth: 3.0	Mouth: 2.67	Mouth: 3.0	Mouth: 1.0

Table D3 Average contamination scores in the eye, nose and mouth areas for each face shield at large manikin head position 3 (colour coding: Grey=0 and 0 < Green < 1 ≤ Yellow < 2 ≤ Red)

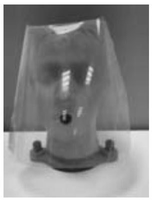
Head orientation	Face shield test results mean of 3 replicates				
					
	PH20194/02	PH20194/15	PH20194/16	PH20194/17	PH20194/18
	Eyes: 0.67	Eyes: 0	Eyes: 2.33	Eyes: 0.33	Eyes: 0
	Nose: 0.67	Nose: 0	Nose: 2.0	Nose: 0	Nose: 0.67
	Mouth: 0.33	Mouth: 0	Mouth: 1.67	Mouth: 0.67	Mouth: 0.33
Position 3: Front and looking down					
	PH20194/19	PH20194/20	PH20194/21	PH20194/22	PH20194/23
	Eyes: 3.0	Eyes: 0.33	Eyes: 0.33	Eyes: 0.33	Eyes: 0
	Nose: 1.67	Nose: 0	Nose: 0.67	Nose: 0.33	Nose: 0
	Mouth: 1.0	Mouth: 0.67	Mouth: 0.33	Mouth: 0.67	Mouth: 1.0

Table D4 Average contamination scores in the eye, nose and mouth areas for each face shield at large manikin head position 4 (colour coding: Grey=0 and 0 < Green < 1 ≤ Yellow < 2 ≤ Red)

Head orientation	Face shield test results mean of 3 replicates				
 Position 4: Left and looking up					
	PH20194/02	PH20194/15	PH20194/16	PH20194/17	PH20194/18
	Eyes: 2.0	Eyes: 0.33	Eyes: 3.0	Eyes: 1.67	Eyes: 0.33
	Nose: 1.33	Nose: 0.67	Nose: 2.33	Nose: 1.0	Nose: 0.67
	Mouth: 1.67	Mouth: 0.67	Mouth: 3.0	Mouth: 2.0	Mouth: 1.0
					
	PH20194/19	PH20194/20	PH20194/21	PH20194/22	PH20194/23
	Eyes: 3.0	Eyes: 2.33	Eyes: 2.67	Eyes: 0.33	Eyes: 2.0
	Nose: 2.0	Nose: 2.0	Nose: 2.0	Nose: 1.33	Nose: 1.67
	Mouth: 2.67	Mouth: 2.33	Mouth: 3.0	Mouth: 2.67	Mouth: 2.33

Table D5 Average contamination scores in the eye, nose and mouth areas for each face shield at large manikin head position 5 (colour coding: Grey=0 and 0 < Green < 1 ≤ Yellow < 2 ≤ Red)

Head orientation	Face shield test results mean of 3 replicates				
 Position 5: Left and looking down					
	PH20194/02	PH20194/15	PH20194/16	PH20194/17	PH20194/18
	Eyes: 0.33	Eyes: 0.67	Eyes: 1.0	Eyes: 0.67	Eyes: 0
	Nose: 0.67	Nose: 0	Nose: 0.33	Nose: 0.33	Nose: 0
	Mouth: 0.67	Mouth: 0	Mouth: 1.33	Mouth: 0.67	Mouth: 0.33
					
	PH20194/19	PH20194/20	PH20194/21	PH20194/22	PH20194/23
	Eyes: 1.0	Eyes: 0.67	Eyes: 0.33	Eyes: 0	Eyes: 1.0
	Nose: 0	Nose: 0.67	Nose: 0.33	Nose: 1.33	Nose: 1.0
	Mouth: 1.33	Mouth: 1.67	Mouth: 1.67	Mouth: 2.33	Mouth: 1.67

Table D6 Average contamination scores in the eye, nose and mouth areas for each face shield at large manikin head position 6 (colour coding: Grey=0 and 0 < Green < 1 ≤ Yellow < 2 ≤ Red)

Head orientation	Face shield test results mean of 3 replicates				
					
	PH20194/02	PH20194/15	PH20194/16	PH20194/17	PH20194/18
	Eyes: 2.67	Eyes: 0.67	Eyes: 3.0	Eyes: 0.67	Eyes: 0.33
	Nose: 2.33	Nose: 1.0	Nose: 2.33	Nose: 0.67	Nose: 0.67
	Mouth: 2.33	Mouth: 0	Mouth: 3.0	Mouth: 1.0	Mouth: 0.67
Position 6: Right and looking up					
	PH20194/19	PH20194/20	PH20194/21	PH20194/22	PH20194/23
	Eyes: 3.0	Eyes: 1.0	Eyes: 1.67	Eyes: 2.0	Eyes: 2.33
	Nose: 2.33	Nose: 0.67	Nose: 1.33	Nose: 1.67	Nose: 2.0
	Mouth: 3.0	Mouth: 1.0	Mouth: 2.0	Mouth: 3.0	Mouth: 2.67

Table D7 Average contamination scores in the eye, nose and mouth areas for each face shield at large manikin head position 7 (colour coding: Grey=0 and 0 < Green < 1 ≤ Yellow < 2 ≤ Red)

Head orientation	**Face shield test results mean of 3 replicates**				
 Position 7: Right and looking down					
	PH20194/02	PH20194/15	PH20194/16	PH20194/17	PH20194/18
	Eyes: 0.33	Eyes: 0.33	Eyes: 1.33	Eyes: 0.67	Eyes: 0
	Nose: 0.33	Nose: 0	Nose: 1.33	Nose: 0.67	Nose: 0.33
	Mouth: 1.33	Mouth: 0.33	Mouth: 2.33	Mouth: 1.0	Mouth: 0.33
					
	PH20194/19	PH20194/20	PH20194/21	PH20194/22	PH20194/23
	Eyes: 1.33	Eyes: 1.0	Eyes: 1.0	Eyes: 0.33	Eyes: 0
	Nose: 1.0	Nose: 0.67	Nose: 1.33	Nose: 0.67	Nose: 0
	Mouth: 2.0	Mouth: 1.33	Mouth: 1.67	Mouth: 1.33	Mouth: 0.67

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