

Do child-size respirators sold in Indonesia and Nepal meet standard adult performance requirements for filtration and air resistance, and requirements as modified for children?

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ABSTRACT

Background: The FACE-UP project (Factors Affecting Childhood Exposures to Urban Particulates) aims to establish ways to reduce the lifetime vulnerability of children in the urban environment to non-communicable diseases by reducing childhood exposure to particulate air pollution. The project focuses on achieving exposure reduction through context-appropriate interventions that can be accomplished personally by individuals and their caregivers, in Nepal and Indonesia. One part of the project, discussed in this paper, involves measuring the efficacy of child-sized respirators marketed as respiratory protection certified to other countries' regulatory respirator standards (KN95, FFP2, and/or KF94). Those respirators meeting acceptable criteria would be put forward for fit-testing on children in a subsequent part of the project.

Methods: Eight children's respirators, selected as being potentially appropriate for respiratory protection, and available in Nepal or Indonesia, were inspected for appropriate features or defects and measured using adapted standard US National Institute for Occupational Safety and Health (NIOSH) methods for pressure drop (breathing resistance) and particulate filtration efficiency of adult respirators. Two certified N95 models, designed for adults, were also measured as reference. The corresponding requirements that might be appropriate for children's respiratory protection were discussed.

Results: Of the eight candidate respirators investigated, six met the particulate penetration requirements from the NIOSH N95 filtering facepiece respirator (FFR) standard, with two others having particulate penetration substantially higher than the maximum threshold specified by the NIOSH standard and by the standards claimed by the supplier, even at the reduced flow rate more appropriate for a children's respirator. All of the tested respirators met the pressure drop requirements specified by the adult FFR standards. One (Purvigor) had a quality control problem (missing nose clips).

Conclusions: The results confirm that there are respirators available in both Nepal and Indonesia that meet the performance requirements of both adult respirator standards and also values adjusted for child physiology. However, since 25% of the models of respirators tested did not meet standard requirements,

the results also emphasized the need for a technical evaluation of products claiming respiratory protection before they are recommended as a potential intervention. When considering the potential for future recommendations for the use of respirators for children in countries such as Indonesia and Nepal, where there is no regulation of the performance or certification claims made by respirator manufacturers, it is apparent that a quality assurance program would be an important component of implementation in order to prevent the use of products that do not perform to an acceptable minimum standard. Due to the physiological and anthropometric differences between children and adults, as well as potential differences in concept of use compared with adults in the workplace, further work is warranted to help define requirements and standards appropriate specifically for children's respiratory protection.

Keywords: children's respiratory protection, urban particulate matter, aerosol protection, flow resistance, particulate protection.

INTRODUCTION

The Factors Affecting Childhood Exposures to Urban Particulates (FACE-UP) project (FACE-UP 2023), launched in 2022, aims to establish ways to reduce the lifetime vulnerability of children in the urban environment to non-communicable diseases by reducing childhood exposure to particulate air pollution (PAP). The research is focussed specifically on children in urban Nepal (Kathmandu) and Indonesia (Bandung). While air pollution is a particularly acute problem in those two cities, children's exposure to PAP is a growing concern in many parts of the world, and worsening due to the increasing incidence of wildfires, dust storms, etc., due to climate change (UNICEF Children's Environmental Health Collaborative 2024). Children are potentially more susceptible than adults to effects from exposure to particulate matter (PM) because of factors that increase either exposure or likelihood of effects, such as time spent outdoors, activity levels, and the developmental stage and differing size of their lungs relative to their breathing minute volume (the volume of air breathed in one minute). As a result, effects on children born and raised in areas of high air pollution include a higher likelihood of developing asthma, reduced life expectancy, and greater likelihood of significantly reduced lung function in adulthood (C40 Cities Climate Leadership Group 2019).

The FACE-UP project has approached achieving exposure reduction through context-appropriate interventions that can be accomplished personally by individuals and their caregivers. The multi-part project involves measuring the efficacy of respiratory protection to reduce exposure, including characterizing PAP exposure resulting from children's daily routines, and fit-testing children with respirators determined to meet standard requirements (Sleeuwenhoek *et al.* 2025). The project also includes an estimation of the reduction of adverse health effects due to reduced exposure to PAP via the use of such child-sized respiratory protection. Further parts of the project examined the contextual, behavioral, policy, and ethical considerations around potential implementation of respiratory protection as an intervention in these countries.

In order to help select the potential respiratory protection products to be used in the face-fit testing investigation, the FACE-UP project team identified eight products marketed for children, claiming to meet respiratory protection standard requirements, and readily available locally in Nepal and Indonesia via on-line marketplaces. Initially three from each country were identified; two more were added for Indonesia when initially selected products gave poor results. Only three were selected for each country for the following reasons. Firstly, there were not many models available from reputable retailers that had a standard printed on them, giving a limited selection from which to choose. Styles that had different shapes and patterns/colours, and were affordable, had been pre-selected as they were also pertinent to other study parameters related to their acceptability to users. Secondly, the intention was to continue on with only three respirator models in each country, in order to prevent overburdening the children during the fit-testing portion of the study (Sleeuwenhoek *et al.* 2025).

Relating to the technical performance parameters for selection, respirator models were considered to be potentially usable as filtering facepiece respirators (FFRs) to help reduce children's exposure to urban PM based on the following criteria: claimed to be a small size or designed for children ages 7-12 years and claimed to meet respiratory protection standards (these being KN95 (Standardization Administration of China 2019), KF94 (South Korean Ministry of Food and Drug Safety 2020) or FFP2 (European Committee

for Standardization 2009)). Because of the prevalence of fraudulent claims and counterfeit items on on-line marketplaces (NIOSH 2022), it was important to examine the items and independently verify important performance claims before selecting the models to be used for the fit-testing study.

The intention of this work was not to propose universal methods or standard performance metrics; the work was focused on a realistic and achievable way to compare products on the market to assist in their selection specifically for the overall study of which this work was a part. Various existing standard approaches were adapted in order to fulfil this objective using methods available to the authors, and available data on the relevant child population used to adapt the performance requirements of standards to them, to support future consideration as to how such standards might be devised.

In the work published here, two important parameters that might affect their suitability were investigated: i) the ability to filter particles in the relevant size range at an appropriate flow rate and ii) the breathing resistance (pressure drop) as air moves through the items under the same conditions. These two parameters were assessed using test methods adapted from requirements in the U.S. Code of Federal Regulations (42 CFR 84 2017) for occupational N95 FFRs. In addition, the items were inspected for any other obvious features or defects that might make them unsuitable for the study.

Literature

A summary of the performance requirements of some of the more commonly used international standards for FFRs is given in Wang *et al.* (2022). Globally, at the time of writing, there is only one standard for child respirators, China's GB/T 38880-2020 "Technical Specifications of Children's Masks" (Standardization Administration of China 2020) which claims to be "applicable to masks for children of age 6 up to age 14, for the purpose of filtering particulates in air, and blocking microbes, pollens, airborne droplets, etc." For the protective mask Class F, it describes a single-use¹ respirator that has adjustable straps, not tied, with a pliable nosebridge, having particulate filtration efficiency better than 95%, and inhalation and exhalation resistance ≤ 45 Pa at 45 L/min. Based on a search of US eCommerce websites at the time of writing, that standard does not appear to be referenced or claimed by manufacturers outside of China, and little has been shared regarding the justification for the performance specifications in the GB/T 38880-2020 standard. There are no global (e.g. International Organization for Standardization (ISO)) or consensus standards for children's respirators, and although there is a growing body of published work claiming relevance to design of respirators for children (Seo *et al.* 2017; Sucipta *et al.* 2023; Zhang *et al.* 2023; National Academies of Sciences, Engineering, and Medicine 2023; Goto *et al.* 2021; Realmuto *et al.* 2023), this knowledge has largely not been translated systematically into practice, although some countries do provide regulatory approvals for respirators designed for children (National Academies of Sciences, Engineering, and Medicine 2023). Few studies have performed relevant performance measurements specifically on respirators claiming to fit children. Seo *et al.* (2023) recently examined pressure drop and particulate filtration efficiency of three styles of children's respirator: KN95 (nonwoven), surgical (nonwoven), and cotton or cotton-blend cloth masks. They measured at two different face velocities equivalent to estimated adult and school-age child breathing volumes for extremely heavy work (85 and 33.7 L/min respectively). As expected, filtration efficiency increased (penetration reduced) and pressure drop decreased at the lower, child-based face velocity. Two studies assessed wearability parameters of selected N95 respirators for children, together including self-reported comfort and measured fit and gas exchange when at rest or performing light exercise (Goh *et al.* 2019; Smart *et al.* 2020). Minimal negative effects of wearing N95 were detected. It should be noted that physiological effects of respirator wear have not been systematically examined at much higher activity rates that might arise for active children, although Smart *et al.* (2020) did record discomfort due to heat buildup within the mask during a running activity.

The basis for the test conditions used in this study is described below, with discussion relating to how these conditions might be relevant to children vs. the conditions used in the US or other accepted standards intended for adults. There are no relevant related US standards for the general public or children (Samet *et al.* 2022), or in Nepal or Indonesia where the fit-testing study (Sleeuwenhoek *et al.* 2025) took place. It should also be recalled that there is no particular specific basis for the filtration efficiency standard values

¹ Recommended single-use.

(common examples being 94 or 95%); they are for comparative purposes only and an item that provides slightly worse filtration efficiency than a proposed value might be considered preferable for other reasons, if not proscribed by regulation. The protection factor in use is actually the most relevant parameter, but again, there is rarely a specific health-based basis for a particular exposure reduction value/protection factor required in standards; rather, different styles of items provide different and often highly variable tiers of protection in use (CSA 2023) and selection is a complicated process of balancing protection and other relevant performance parameters.

Airflow resistance (pressure drop)

Airflow resistance, or pressure drop, is an important performance requirement because the resistance that air meets as it flows through the respirator correlates with the work of breathing required by the wearer to move air through the respirator materials. Lower pressure drops correlate with easier breathing through the respirator. The pressure drop requirements of the particulate filtering facepiece respirator standards discussed in this article – KN95, FFP2, N95, KF94, and Class F – are outlined in Table I.

Table I. Pressure drop requirements of selected particulate FFR standards.†

Flow condition (L/min)	Maximum permissible pressure drop (Pa)	Requirement	Standard source
Inhalation 85	343 (35 mm H ₂ O)	N95	U.S. Code of Federal Regulations (42 CFR 84 2017), Section 84.180
Exhalation 85	245 (25 mm H ₂ O)		
Inhalation 30 Inhalation 95	70 240	FFP2, KF94	EN 149-2001, European Committee for Standardization (2001) South Korean Ministry of Food and Drug Safety (2020)
Exhalation 160	300		
Inhalation 85	350	KN95	GB2626-2019, Standardization Administration of China (2019).
Exhalation 85	250		
Inhalation/exhalation 45	45	Class F	GB 38880-2020, Standardization Administration of China (2020)

† Inhalation and exhalation pressure drops will be identical for a FFR with no exhalation valve, as for models tested here; therefore for this study, the lower number of the two (exhalation/inhalation) measured at the same flow rate will set the permissible pressure drop requirement.

Compared with adults, the maximum inspiratory and expiratory pressures of children are higher (Szeinberg *et al.* 1987); airway resistance decreases markedly as humans grow and airways increase in volume – the airway resistance of infants is 19 to 28 cm H₂O/L/s (1900 to 2700 Pa/L/s), whereas in adults it is less than 2 cm H₂O/L/s (<200 Pa/L/s) (Insoft and Todres 2009). No evidence could be found in the literature for whether children tolerate similar pressure drops as adults through face-worn items. As discussed below and as previously reported (Seo *et al.* 2017), the smaller minute volume breathed by children would result in a reduced flow rate through respirator material compared to the flow rate of adult breathing and would therefore result in lower pressure drop. In general, lower pressure drop means increased breathability and comfort, related to the work of breathing (Xu *et al.* 2021, International Organization for Standardization 2023).

Particulate penetration

For an N95 (section 84.174 of CFR (2024)) or KN95 (Standardization Administration of China 2019) respirator, with the specified particle size distribution of $0.075 \pm 0.020 \mu\text{m}$ and geometric deviation not exceeding 1.86, the maximum permitted penetration is 5% at 85 L/min flow (corresponding to a filtration efficiency greater than or equal to 95% at approximately the most penetrating particle size). Similarly, for a

KF94 (South Korean Ministry of Food and Drug Safety 2020) or FFP2 (European Committee for Standardization 2009), the maximum permitted penetration is 6% at 95 L/min, while for an FFP3 it is 1% (European Committee for Standardization 2009).

METHODS

General

All equipment used was calibrated according to manufacturer's recommendations or established standards.

Test models

The various respirator models evaluated for performance (eight test models, and two reference N95 respirator models used for the purposes of this study) are described below. The characteristics of the samples are described in Table II.

The eight test models were chosen based on availability in Indonesia or Nepal, and their claims to meet a performance standard, and variation in other usability characteristics, with two added later due to poor performance of two originally chosen. The two reference adult N95 models, meeting the N95 filtration efficiency and pressure drop requirements, were available in the test laboratory. They had quite different construction to each other (one was a hard cup shape, the other made from soft materials in a pleated design); the method could be applied successfully to both. Use of two reference models also demonstrated the replicability achievable in the methods when testing such models that had met appropriately verified quality control against a performance standard.

Sample preparation

A minimum of 3 replicate items of each model was measured, more (up to 5) where results appeared less replicable (as illustrated later in the results for some of the models under investigation compared with the reference models). Selected samples were also measured repeatedly on different days for assurance of replicability of the measurement (data not shown, only those models discussed later had poor replicability).

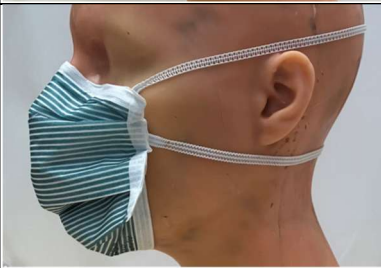
It was not practical to measure performance on the entire item as is done using the NIOSH method (NIOSH 2016) which is designed for a particular adult respirator size and construction and uses a specific test instrument. Instead, a filter sample cutout was used, and the results scaled as appropriate to yield values that could be compared with the standard. All fittings, straps, and supporting/reinforcing materials were removed so that only the filtration layers remained. The filtration layers were weighed, this result representing the total active (breathable) surface area of the item that would be tested if following the NIOSH method. From each item's filtration layers, one or two 67 mm diameter circle cutouts were cut and weighed, yielding the areal density of the filtration layers (g/cm^2); the first three cutout replicates measured were from three different items. Subsequent replicates (4 and 5) if tested may have been cut from these same three initial respirator items (one or two could be obtained per sample depending on model design) or from new replicate respirators if required. The resulting areal density was used to calculate the mass of the filtration layer in the aperture of the sample holder (built at RMC, to hold a 67 mm diameter cutout with a 31 mm diameter aperture, Figure 1). The calculated mass of the sample within the 31 mm diameter aperture was compared to the total mass of the active filtration layer for the item, generating a correction factor that could be used to yield the equivalent flow that would have passed through the estimated entire active surface had the whole item been measured.

The results of the correction factor calculation are given in Table III. The largest source of error in the measurement depends on the trimming of the item and the cutout; the estimated error for the correction factor, which determines the flow rate equivalency for the measurement, is 10%.

Table II. Sample characteristics.

Manufacturer/Model	Claimed certification†	Type of fit	Nose fitting	Straps	Size	Appearance	Reason for inclusion
Fit-U-Mask	KN95/FFP2	Folding vertical	Bendable double wire clip	Ear loop	Kids		Available in Indonesia
Pokana	KN95	Folding vertical	Bendable clip	Ear loop	Kids		Available in Indonesia
Jinjiang	GB2626-2019 KN95	Folding vertical	Bendable clip	Ear loop	Kids		Available in Nepal
Purvigor	GB2626-2006 KN95 (obsolete)	Folding vertical	None (slot that should have contained bendable clip was empty)	Ear loop	Kids		Available in Nepal

Manufacturer/Model	Claimed certification†	Type of fit	Nose fitting	Straps	Size	Appearance	Reason for inclusion
						 Embossed stamping in centre of facepiece breathing area on each side; bendable nose strip missing on all samples	
Double A Care	GB2626-2019 KN95	Folding horizontal	Bendable clip	Ear loop	Kids		Available in Nepal
CAREION	No packaging but KN95 claimed on-line	Folding vertical	Bendable clip	Ear loop	Kids		Available in Indonesia
Schemafirst	FFP3; Type IIR EN 149:2001 + EN 14683 + AI:2009	Folding vertical	Bendable clip	2x headstrap	S		Available in Indonesia

Manufacturer/Model	Claimed certification†	Type of fit	Nose fitting	Straps	Size	Appearance	Reason for inclusion
OnCare	KF94	Folding horizontal	Bendable clip	Ear loop	Kids		Available in Indonesia
Moldex Series 1500	N95	Hard cup	Foam	2x headstrap	Adult M		Reference model
AlphaProTech N95	N95	Folding	Bendable clip	2x headstrap	Adult one-size		Reference model

† N95 – US CFR (2024). GB2626-2019 - Standardization Administration of China (2019). KN95, KF94: South Korean Ministry of Food and Drug Safety (2020). FFP3: European Committee for Standardization (2009). EN 149:2001: European Committee for Standardization (2001). EN 14683: European Committee for Standardization (2019).

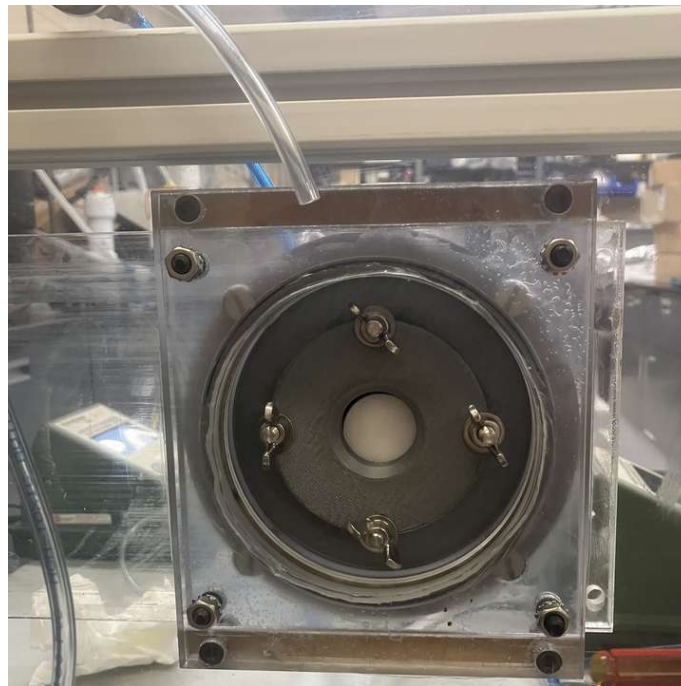


Figure 1. Sample (centre white portion) in sample holder, viewed from inside test chamber containing aerosol test medium. The tubing inlet that samples the chamber concentration near the filter sample inlet is seen above the sample holder.

Test flow rate

The flow rate of 85 L/min (CFR 2024) is not particularly representative of typical children's breathing patterns given it is based on adults performing heavy work. In this work alternate challenge flow rates were explored based on a size and body weight adjustment. In addition to the standard challenge flow rates of 85 and 95 L/min, three additional challenge flow rates (39, 50, 63 L/min) were derived, to be more representative for children 7, 10 and 13 years old.

The flow rate of 85 L/min has been based on adults, characteristic of men in some Asian populations and standard women (ISO 2022a) performing continuous heavy work for up to 15 minutes. According to the ISO standard (2022a), the correction of the breathing parameters by body size (to correct the published adult data to those for 7-13 year-olds) can be performed using the body surface area. Median height data from Africa, Europe and Asia for males and females ages 7, 10 and 13 (Haas and Campirano 2006) were used in combination with a median body mass index (male/female average) (World Health Organization 2025) and corresponding weight that was reverse calculated from the Centers for Disease Control body mass index calculator (2022). An estimated median surface area is derived using the nomogram in Haycock *et al.* (1978) (Table IV). The relevant values of minute volume from the ISO standard (2022a), by body surface area, are given in Table VTable, and extrapolated for the body surface area of children, as derived from Figure 2.

Table IV. Estimation of body surface area for 7-13 year-olds based on height and weight.

Age (years)	Median height (cm)	Median body mass index (kg/m ²)	Median weight (kg)	Surface area (m ²)
7	124.5	15.5	24.1	0.9
10	143	16.5	34.5	1.16
13	160	18.7	48.2	1.45

Table V. Minute volume from ISO 16976-1 (ISO 2022a) as a function of body surface area, and extrapolated/estimated values for children.

Person	Body surface area	Class 5 minute volume (very heavy work)	Class 7 minute volume (extremely heavy work)
	m ²	L/min	L/min
Small adult	1.69	45	73
Medium adult	1.84	49	80
Large adult	2.11	56	91
Median 7 year-old	0.9*	24**	39**
Median 10 year-old	1.16*	31**	50**
Median 13 year-old	1.45*	39**	63**
* estimated values from calculation			
** linearly extrapolated values from adult (Figure 2)			

This extrapolation yields a minute volume of about 40-60 L/min for children in the 7-13 years age range at the Class 7 metabolic work rate (ISO 2022a), while the values given by Seo *et al.* (2023) for 6-11 year-olds based on literature are in the 20-40 L/min range, with an average of about 35 L/min. Work rate Class 5 is perhaps more likely as a maximum for active children, which is intense activity at a fast pace including climbing and running, and yields values more comparable to those of Seo *et al.* (2023) that are stated to correspond to 'heavy exercise' (ISO 2022a). The Class 5 minute volume of 39 L/min for a median 13 year-old was chosen as a relatively conservative representation of children's flow rate at a heavy work rate.

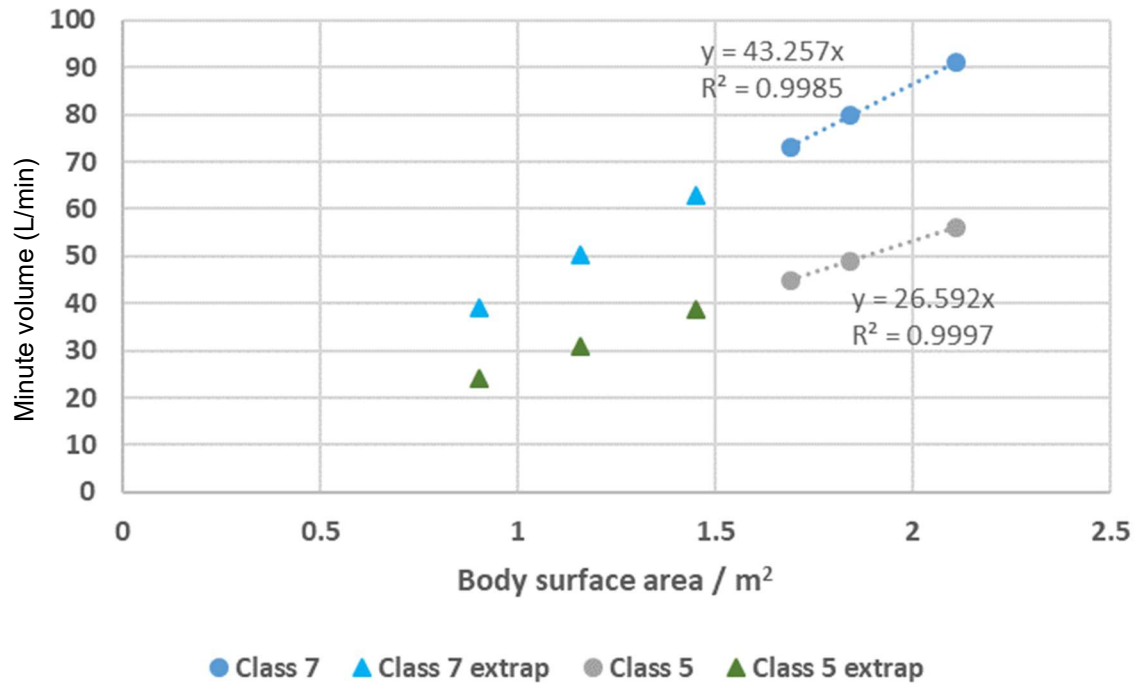


Figure 2. Respiratory minute volume for two ISO 16976-1 (ISO 2022a) classes of work rate, namely Class 7: extremely heavy work for 15 minutes, and Class 5: very heavy work, as a function of body surface area, and extrapolated (from fitted dotted lines) to body surface areas representative of children 7-13 years of age.

Preconditioning

Prior to testing for filtration efficiency and pressure drop, each filter cutout was preconditioned at 38 °C and 80% relative humidity for 24 h as per the NIOSH N95 method (NIOSH 2016), and stored for not more than 3 hours in an airtight container immediately prior to use.

Particulate penetration and air flow resistance (pressure drop)

The method was based on the NIOSH test method for N95 respirators (CFR 2024, NIOSH 2016) (Figure 3 shows a layout of the measurement apparatus), and with the necessary standardization of particle size distribution, with the following changes and details.

As discussed above, rather than measurement of the entire respirator as per the NIOSH method (which would have required a custom sample holder for each respirator type, to which each individual sample could be glued or otherwise sealed), a cutout from the facepiece was used, and sealed into a sample holder using rubber gaskets on each side. This methodology was generally more flexible for the quite variable sizes and shapes of the styles to be tested.

Two TSI model 8026 particle generators were used to generate a salt aerosol from an aqueous salt solution, approximately 0.27 µm mass median aerodynamic diameter (as measured using combination of an aerodynamic particle sizer TSI model 3321, and scanning mobility particle sizer TSI model 3938, all TSI, Shoreview MN USA). The aerosol was not neutralized but rather continuously generated in a large test chamber (1.2 x 1.2 x 2.2 m³) to a concentration of 60,000 ± 15,000 particles/cm³ with a gentle circulating fan to maintain constant concentration throughout the chamber, as measured on the 'ambient' channel of a TSI PortaCount™ 8020M condensation nucleus counter (before and after each penetrated aerosol

measurement). The penetrated aerosol through the filter sample was measured on the 'sample' channel of the same counter. The response of the two channels was the same within 5% as determined during calibration. Each aerosol measurement was averaged over 10 seconds (10 readings). Results that were apparently poorly replicated between different cutouts or showing unusually high penetration were checked carefully. In no case was there any evidence for leakage around the sample or any other source of unexpected results, and all such data were retained. This method, which uses particle count number to determine filtration efficiency rather than particle mass as in the NIOSH method, was easily available and is widely used to measure fit factor and protection factor, as it would be used in the later study (Sleeuwenhoek *et al.* 2025). These two methods (count vs mass-based) do yield slightly different values but the trend depends on the details of the construction of the filter media (Sipkens *et al.* 2022); however, as the typical requirements values of 95% filtration efficiency in various standards have no actual basis in the required protective levels of the device for any given hazard a count-based method has generally similar merit when trying to estimate the protective performance of the various styles for the purposes of selection in the context of this study.

The filtration efficiency as a function of accumulation of aerosol in the filter over time was not measured, as the salt concentration was too low to result in any significant accumulation. Each sample took approximately 30 minutes of continuous testing at various flow rates.

Figure 3 illustrates the test set-up. For each test cutout sample measured, flow rates (generated by a GAST Regenair blower, model R1102) were varied over the range of approximately 1-8 L/min through the cutout (measured using a TSI model 4045 flowmeter), corresponding to a range for a given respirator type of about 30-100 L/min. A high efficiency (HE) particulate filter was placed in the exhaust flow stream to clean the air and protect the measurement equipment. The pressure drop at each flow rate, in mm H₂O (Durham Instruments, Newark GA100-005WD pressure sensor, up to 127 mm H₂O), was also recorded in each case. The sampling flow rate of the PortaCount™ 8020M at 100 mL/min was added to the flow rate reading from the digital flow meter to calculate the total flow through the exposed area of the sample cutout. Ambient temperature and relative humidity were 22 ± 1 °C and 20 ± 5 % RH.

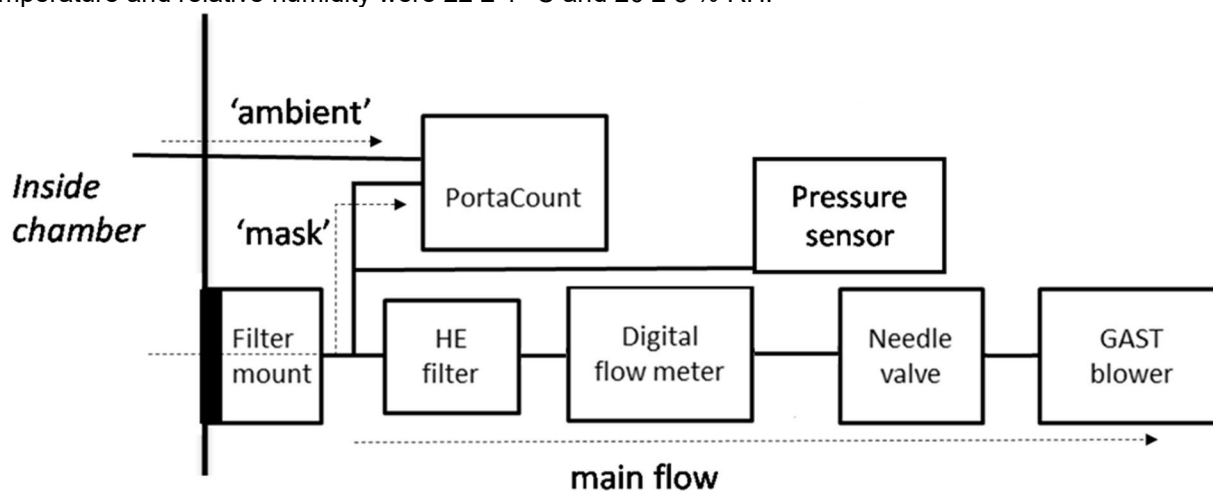


Figure 3. Block diagram of measurement apparatus for filtration efficiency and pressure drop.

The error on the flow rate reading is 2% of the reading, per the flowmeter manufacturer. Based on replicate measurements on the same cutout using the same flow rate on different days, the error on the penetration (the average 'in-respirator' reading divided by the average 'ambient' reading, expressed as a percent) was about 5% of the calculated penetration value, and ± 0.1 mm H₂O on the pressure drop. The same sample measured on different days yielded very replicable data. Replicate cutouts did not necessarily yield similar results, based on individual sample characteristics, as discussed later.

RESULTS

Air flow resistance (pressure drop)

In all cases, for a given cutout, the measured pressure drop as a function of test flow rate was linear, passing through zero (example results in Figure 4). For most of the measured respirator types, the pressure drop was very reproducible across replicate samples (see for example Figure 4a and b), but for a few, the replicability was considerably lower (for example, see Figure 4c); the presumed reason for the poor replicability for the Schemafirst sample is illustrated in Table II, where the impressed stamp in the centre of each side that would have prevented air penetration where the stamp was impressed can be seen. There is no 'acceptable' amount of replicability in principle, however stamping in the centre of the breathing area might be considered a poor design choice with the potential to affect both the breathing resistance and the integrity of the filtering medium. The air flow resistance results for the two N95 respirators was consistent with their certification.

It can be seen in Figure 5 that in no case is the estimated pressure drop greater than the 25 mm H₂O at 85 L/min permissible under the US CFR (CFR 2024) although the Pokana was just under this value. At the lower equivalent flow rate of 39 L/min more representative of a 7 year-old, the pressure drop is correspondingly lower.

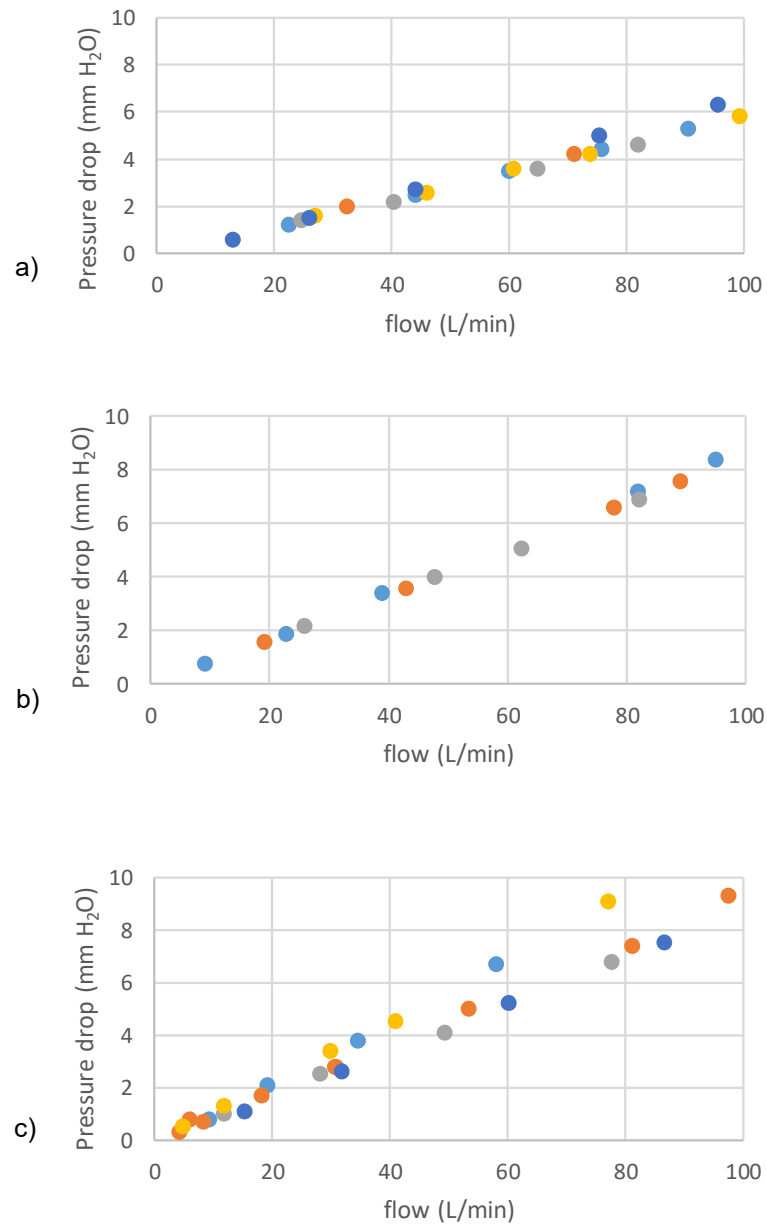


Figure 4. Pressure drop vs. flow rate for a) AlphaProTech N95 respirator, b) Jinjiang , and c) Schemafirst. Each colour represents a different replicate sample.

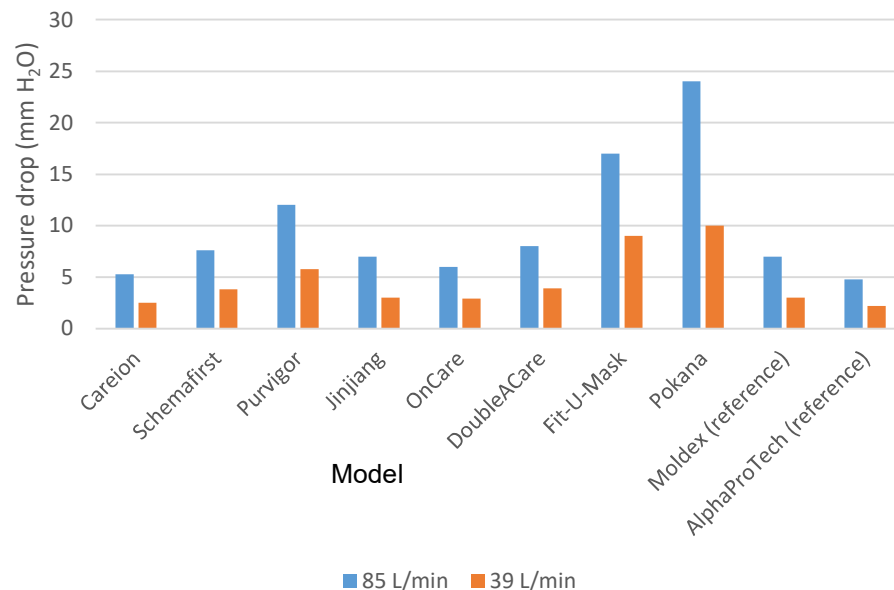


Figure 5. Estimated pressure drop for the sample respirators at the equivalent flow rates specified, based on interpolating values on graphs such as those presented in Figure 4.

Particulate penetration

Example results for particulate penetration as a function of flow rate are given in Figure 6. For the majority of the sample respirator materials, the penetration was linear with flow rate passing through zero (see Figure 6a) for a typical example), with one exception, the CAREION sample (see Figure 6b); for this filter material, the initial penetration at very low flow rate was very high and the 5% threshold was exceeded almost immediately. There is no obvious explanation for the poor behaviour of these samples if their claimed certification was met. For the Schemafirst sample, again variable and poor results were obtained (Figure 6c), presumably again due to the imprint in the centre of the sample that could have caused disruption of the material barrier properties.

The summary results for particulate penetration at the two equivalent flow rates for all the tested samples are given in Figure 7.

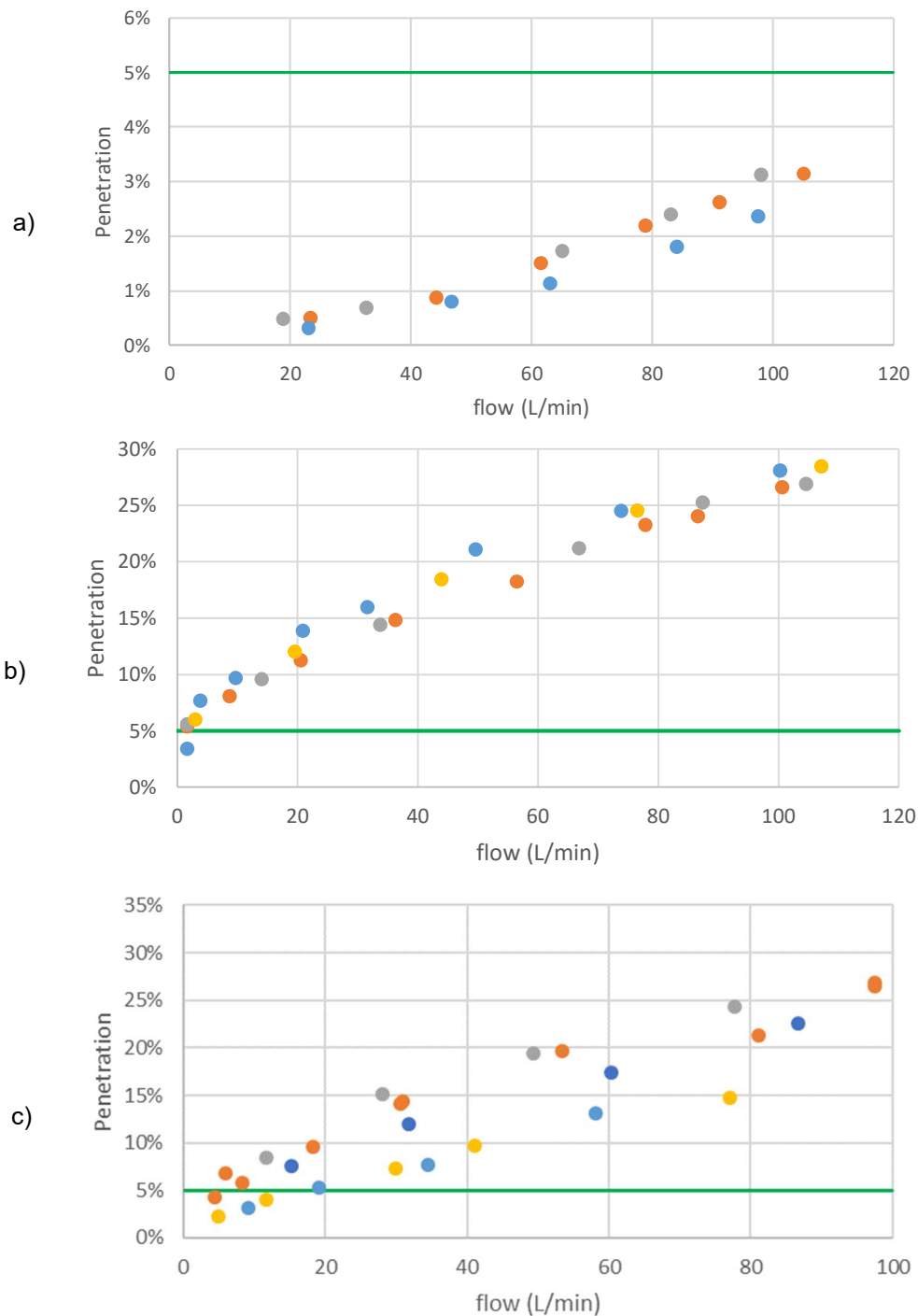


Figure 6. Example particulate penetration results for a) Pokana showing typical linear behaviour of most models; b) CAREION, showing non-linear behaviour and poor performance; and c) Schemafirst, showing variability and poor performance. The different colours represent different replicate samples. The green line represents 5% penetration.

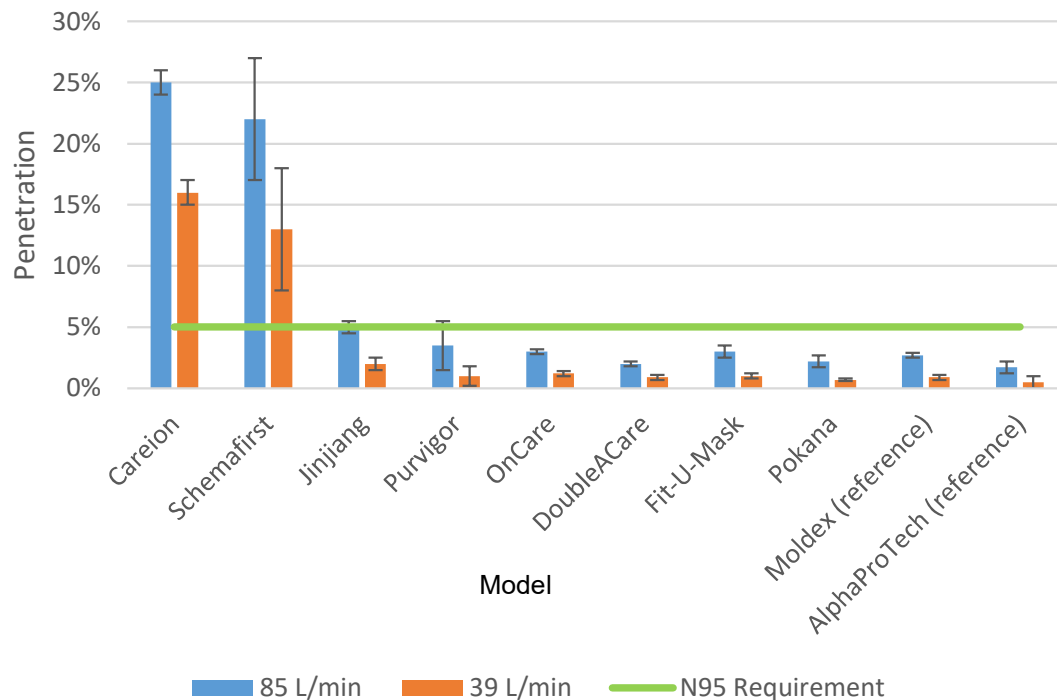


Figure 7. Particulate penetration at the specified equivalent flow rates. The solid line shows the N95 requirement at 85 L/min.

The six proposed models that yielded particulate penetration results using this test method that were reasonably consistent with their declared certification at higher flow rates were the Purvigor, Jinjiang, Double A Care, all available in Nepal, and Fit-U-Mask, OnCare, and Pokana, all available in Indonesia.

The performance of the N95 models measured using these methods was consistent with their certification.

Other observations

The Purvigor samples were missing the nose clips from the (sealed) slot that should have contained them, indicating quality control issues. Purvigor also declared certification to an obsolete standard version.

The Schemafirst samples provided had headstraps (although a model with ear loops is also available according to the on-line information). Ear loops are generally assumed to be preferable for ease of use although not necessarily for comfort, and conclusions drawn from adults may not translate to children (Mumma *et al.* 2023); they are also almost ubiquitously available for children's KN95 respirators in both Nepal and Indonesia based on the team's investigation when sourcing the models.

DISCUSSION

Based on the sum of all the observations, the models that performed appropriately against filtration efficiency standards and had required characteristics such as nose clips were Jinjiang and Double A Care (Nepal), and OnCare, Pokana and Fit-U-Mask (Indonesia). The other models had questionable performance or features, emphasizing the need for a technical evaluation of the specific models that are under consideration for recommendation as respirators for children's use.

In this study, two of the models (both from Indonesia) had penetration values vastly in excess of N95 requirements (and those of similar certifications in other jurisdictions). The CAREION model was visually different from the other models. As seen in Table II, it was a patterned respirator with online/packaging information that it was certified to KN94 standard and was 4-ply. On visual inspection, the material was noticeably thinner than the other models. It is possible that this was an example of a mask that had been labelled as having passed a certification when it had not (for example because it had never been tested, or had been altered since certification). The other model that exceeded the N95 penetration threshold was the Schemafirst model. This model had the appearance of a respirator but, as discussed, the FFP3 certification and logo stamped on the material, on both sides of the model, appears to have affected its filtration efficiency, and substantially affected the penetration. Manufacturers should be made aware that such actions can adversely affect the performance of their respirators. Neither of these two models were put forward to the fit-test stage of the FACE-UP study. They were replaced, instead, by the Fit-U-Mask and Pokana models, in Indonesia.

The third model which was not recommended for the FACE-UP fit test study was the Purvigor. This model was missing a nose clip. Given that the penetration for this model was sufficient, and that the model was being sold in Nepal despite not containing a nose clip (the study researchers checked a number of batches), it was decided to include this model in the fit test trial. Further explanation of this and the results of the trial are available in Sleuwenhoek *et al.* (2025).

The study reported here was focused only on pre-selection of models that met reasonable technical performance, and not protection in use. Filtration and pressure drop are important aspects of respirator performance, but without an effective seal to the face, inhaled air will bypass the filter. Some form of fit-testing and training is crucial in order to be able to correctly assess the capabilities of these items when properly used. In the follow-on FACE-UP study, Sleuwenhoek *et al.* (2025) found that, for most of the models tested, the fit factor was low (less than 10), however even fit factors of 2 to 4 give a 50-75% reduction in exposure, which is substantial in a public setting. In terms of training, the FACE-UP study has produced an animated video for children and a booklet for parents/teachers to demonstrate how to properly fit respiratory protection, including the use of ear-loop clips to better hold the respirator onto the face (which resulted in an increased fit factor) (FACE-UP 2025).

Additionally, it is important not to confound the respirators' measurable capabilities with other complex aspects of potential implementation, such as whether compliance with proper selection, use and maintenance procedures can be expected. When considering the potential for future recommendations for the use of respirators for children in countries such as Indonesia and Nepal, where there is no domestic certification system, it is apparent that some form of quality assurance program would be an important component of implementation, in order to prevent the use of products that do not perform optimally.

Finally, due to the physiological and anthropometric differences between children and adults, as well as potential differences in concept of use compared with adults in the workplace, further work to help define requirements and standards appropriate specifically for children's respiratory protection is warranted. For example, collectively, respiratory effects (e.g., wheeze, cough, respiratory hospital admissions) from short-term exposure to particulate matter of all size fractions are increased in children (i.e., < 18 years) compared with adults (Sacks *et al.* 2010). This may imply a need to set more conservative protection requirements for child respirators than one might propose for adult respirators. Such a higher protection requirement might suggest that selecting a higher filtration efficiency would be desirable, although only if combined with a correspondingly more effective fit (as leakage around the respirator may be the determining feature for adequate protection in use), and while maintaining an acceptable breathing resistance.

Limitations

As has been mentioned, the primary intent of the study was to aid in selecting appropriate respirators for the next phase of the study, by screening out any models that had major technical performance shortcomings or issues. As such, the methods used appeared to be able to perform such screening

adequately. Some of the negative observations, such as the likely effect of the manufacturer's branding stamp on the Schemafirst respirator in creating variability in the outcomes, might have been less apparent if the entire item had been measured as it is in the NIOSH method.

CONCLUSIONS

The COVID-19 pandemic resulted in a proliferation of respirator products marketed for children. Few studies have tested the filtration efficiency of these products and, therefore, whether they meet the stated standards on their packaging. This study tested 8 models claiming to have passed respirator certification standards in various jurisdictions, all marketed as being suitable for children. The models were bought in Indonesia and Nepal, from reputable online marketplaces or pharmacies, and were compared to two N95 respirators for filtration efficiency and pressure drop (breathing resistance).

Six out of eight models met the penetration requirements, and one of these models met the requirements but was missing a nose clip. All of the models met the pressure drop requirements. The observations that 25% of the models (2 out of 8 products) performed poorly relative to the others and typical standards requirements on the filtration efficiency tests, and a further model was missing the nose clip, highlight that there are likely many models world-wide marketed as respirators for children - and adults for that matter - which either have not passed certification (or been tested) or which have design features which compromise the ability of the respirators to filter particles or fit properly. Given that it would be impossible for the public to discern which labelled products actually meet the claimed standards, there is an urgent need for international design standards for children's respiratory protection and quality assurance and control processes in countries stocking these products.

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