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Assessment of the fit and wearability of commercially available KN95 respirators for children in Indonesia and Nepal

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ABSTRACT

The purpose of this study was to determine how well KN95 respirators, marketed for children, fit the faces of children aged 6–13 years old in two urban sites with elevated levels of air pollution: Kathmandu, Nepal and Bandung, Indonesia. The wearability of the tested respirators and the children's style preferences were also assessed.

Sixty children, 30 in each country, were recruited and were fit tested with three different ear loop respirators in two combinations (with and without an additional adjustable ear loop clip worn around the head). The fit factor for each respirator was determined using a modified fit test protocol for filtering face piece respirators using a TSI PortaCount™ Respirator Fit Tester 8048. Facial dimensions were measured using callipers. The wearability of the respirators and children's style preferences were assessed through questionnaires administered after the fit tests.

Most fit factors were less than 10, i.e. less than 90 % reduction in exposure. In both countries, using an additional ear loop clip was associated with increases in fit factor of 42 and 50 % for Indonesian and Nepalese respirators, respectively. There were no significant differences among the respirators for any of the perceptions: comfort, feeling hot, breathability, fit, embarrassment or appearance for either country. The appearance of the respirator was important to the children. Although the use of an additional ear loop clip improved the fit, the respirators were generally too large for the children's faces to achieve a good fit. Respirators marketed for children should be better designed to suit their facial dimensions.

1. Introduction

Exposure to outdoor ambient air pollution, and particularly $PM_{2.5}$ (particulate matter with a diameter of 2.5 μm or smaller) is recognised globally as being a major cause of disease and premature death, with children being one of the most susceptible populations (HEI, 2024; Lelieveld et al. 2023; WHO, 2021). It has been estimated that, every day, around 93 % of the world's children under the age of 15 years (1.8 billion children) breathe air that is so polluted it puts their health and development at serious risk (WHO, 2018; WHO, 2018a). The total number of annual deaths attributable to air pollution has been reported to be 8.1 million in 2021, with 709,000 being in children under 5 years old (HEI, 2024). In addition to mortality, air pollution can adversely affect the health of children in numerous ways, including adverse birth outcomes, mental and motor development, childhood obesity, lung function, respiratory infections, asthma, and childhood cancers such as retinoblastomas and leukaemia (WHO, 2018). Populations from low- and middle-income countries are exposed to 1.3 – 4 times higher levels of ambient $PM_{2.5,}$ compared to those in high-income countries (HEI, 2024). In 2021, air pollution was the second leading risk factor for early death worldwide for children under five (HEI, 2024).

Most sources of outdoor air pollution are well beyond the control of individuals and, as such, there is a demand for concerted action by local, national and regional level policymakers to introduce and implement

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policies that can successfully bring about a reduction in air pollution. The development and implementation of such policies, and consequently the reduction of emissions at source is, unfortunately, a slow process. Carers may therefore resort to other personal-level strategies to reduce their children's exposure to particulate matter.

It is evident that the availability and use of masks, including face coverings (e.g., made of cloth), facemasks (e.g., surgical masks) and respirators (certified to respiratory protection standards to filter ~95 % of particles sized 0.3 μm, such as KN95 [China], N95 [US] and FFP2 [EU/UK]) to protect against outdoor particulate pollution has increased (Zhang and Mu, 2018; Horwell et al., 2019; Le et al., 2023). In addition, the COVID-19 pandemic also greatly increased demand for, and awareness of, masks for public use (Greenhalgh et al., 2020, 2024). Wearability (e.g., comfort, how hot, easy to breathe) of the mask will also play a role in the acceptability of the mask by the child (Le et al., 2023; Preest et al., 2024). Evidence is therefore needed about the efficacy of masks marketed to protect children against PM exposure, as well as their ability to fit children's faces and the likelihood of uptake by children due to their perceived wearability.

There are many published studies relating to respirator and mask efficiency and wearability in adults, particularly because of the recent COVID-19 pandemic, and these include non-workplace settings. However, there are few published studies on respirator and mask fit and wearability relating to children. Recently Fakherpour et al. (2023) published a systematic review of fit test pass rates of masks and respirators. Respirator brand/model, style, gender, ethnicity, facial dimensions, age, reuse and comfort were among the factors identified as having most influence on respirator fitting. However, Fakherpour et al. (2023) identified only one paper relating to masks specifically designed for children (Goh et al., 2019). Goh et al. (2019) evaluated the safety, fit and comfort of a specially designed paediatric N95 mask in 106 children aged 7 to 14 in Singapore. Although fit factors are not reported, they report that all passed the fit test based on the fit factor EN 149:2001 + A1:2009 FFP2 standard. They evaluated the safety of the respirator with and without a micro ventilator fan by measuring end-tidal carbon dioxide and reported that it was well fitting, comfortable and safe for use in children at rest and on mild exertion, although a small number of children reported mild breathing difficulties. Smart et al. (2020) assessed the wearability of N95 respirators in primary school children aged 8–11 years during different walking and running exercises. The design, hotness and perceived breathability affecting the children's perceptions of the masks was studied. The importance of mask design was also highlighted by children in a study by Preest et al. (2024).

The Factors Affecting Childhood Exposures to Urban Particulates (FACE-UP) project aims to reduce the lifetime vulnerability of urban children to noncommunicable diseases by reducing childhood exposure to particulate air pollution through suitable personal interventions (https://face-up-consortium.webspace.durham.ac.uk/about-us/). The FACE-UP study took place in two urban sites with elevated levels of air pollution, these being Kathmandu, Nepal to and Bandung, Indonesia (Carson, Unpublished results).

This part of the FACE-UP project investigated how well respirators, marketed for children and independently verified as passing KN95 filtration efficiency tests (Gudgin, Unpublished results), fitted the faces of children aged 6–13 years old. A secondary aim was to determine how the use of an additional ear loop clip affected the fit of the respirator on the children's faces. The wearability of the respirators and the children's style preferences were also assessed.

2. Materials and methods

The study took place in two urban sites with elevated levels of air pollution: Kathmandu, Nepal and Bandung, Indonesia. These urban sites are described in more detail in Carson et al., (Unpublished results). Face fit tests took place between 28th July and September 6, 2023 in Indonesia and 24th August and October 8, 2023 in Nepal. The protocol for the study, which provides full details of the recruitment, experimental procedures and questionnaires administered, is provided in Supplementary Material 1, however the key points are summarised in the following sections.

Ethical approval

Ethical approval was obtained from the Durham University Ethics Committee (reference number PSYCH-2022-06-01T12_54_54-dps0jac), the Ethical Review Board of the Nepal Health Research Council (NHRC) (reference number 1773/2023) and Bandung Institute of Technology (reference number KEP/II/2022/X/M240123DSA/FACE).

2.1. Participant recruitment

Children were recruited from four schools in total. In each city, children were recruited from a public school (this being a school financed by the government) and private school (this being financed by educational fees paid directly to the school, typically by the child's guardian). The socioeconomic range of the private schools, as reported by the school, was middle to high in both locations, with the public schools in Kathmandu and Bandung having a mixed and low-to-middle range respectively.

The schools were asked to assist in identifying children eligible for the study and, as far as possible, recruiting an equal distribution of girls, boys, and age ranges. Informed consent was provided by parents/carers with the children also providing assent. The aim was to have 30 participants from each country. The initial age range for recruitment was 7–12 years old, later amended to 6–13 years old (approved ethics application amendment) due partly to inconsistencies in date of birth provided by carers and information held by the school. One child also turned 13 between completion of the demographic questionnaire (completed at the time of consenting to participate in the FACE-UP project) and the respirator testing. Any children with known respiratory or back problems (as reported by their parent/carer) were not eligible to participate in the study, to minimise any potential risks from the testing. Participants were free to withdraw from the study at any time.

2.2. Respirator selection

Details of the disposable respirators used in the face fit tests are shown in Table 1. The respirators used were all marketed for children and were chosen based on availability in the local settings in both Nepal and Indonesia, in pharmacies, shops and online. All had KN95 or equivalent rating stated on the packaging, and some also had the regulation printed (e.g., GB2626-2019 for KN95). All were independently verified as passing N95 filtration efficiency tests (Gudgin Dickson et al., submitted). All had ear loops and were supposed to have nose clips. However, during the filtration efficiency tests, it was observed that the Purvigor respirators had no nose clip inside the pouch designed for the clip and this was also the case for all other Purvigor respirators purchased. As these respirators are sold and worn in Nepal without nose clips, and no additional respirators with KN95 (or the equivalent standard) were identified for filtration efficiency testing within the timescale of the project, these respirators were retained for the study.

It is becoming common for people, especially females wearing hijabs, to use an additional strap/clip to tie masks (of any kind) with ear loops to the back of the head. This is either to improve the fit or, where a hijab is worn, to allow the mask to be worn on the outside of the hijab without putting the loops over the ears. Some masks aimed at public use are supplied with such a clip (although none were in our study). Each respirator was tested twice by all participants: once without an additional ear loop clip and once using the clip. The additional ear loop clip used in both locations was a simple, lanyard style clip which attached to the ear loops of the respirator and had an easily adjustable press button

Table 1
Characteristics of the respirators tested in each country.

Respirator name	Standard[a]	Regulation[a]	Image[b]	Colour	Pattern	Fold
Indonesia						
Oncare Masker KF94 Kids	KF94	–		White	No	Horizontal
Pokana KN95 Kids Mask	KN95	–		Grey	No	Vertical
Fit-U Mask	KN95/FFP2	–		Black	No	Vertical
Nepal						

(continued on next page)

Table 1 (*continued*)

Respirator name	Standard[a]	Regulation[a]	Image[b]	Colour	Pattern	Fold
Jinjiang, without valve, child's protective mask	KN95	GB2626-2019		Blue	Yes – cats	Vertical
Purvigor, KN95 mask for children	KN95	GB2626-2006/GB/T38880-2020		White	No	Vertical
Double A Care, Kids Premium KN95 mask, willow-leaf model	KN95	GB2626-2019		White	No	Horizontal

[a] Standard and regulation as stated on respirator packaging, and sometimes on the respirator. Not all respirators had the regulation on the packaging and these have been left blank.
[b] Photographs taken on a size small adult ISO head form (ISO, 2022), built at the Royal Military College of Canada.

to allow for the strap to be the adjusted to the size of the head (Fig. 1).

2.3. Experimental set up

Respirator testing was completed at the child's school over two occasions. The first session involved measurement of the child's facial features, testing of three respirators (either with or without the additional ear loop clip) and administration of a wearability questionnaire after each fit test. The second session involved testing of the remaining three respirators (either with or without the additional ear loop clip), administration of a wearability questionnaire after each fit test, with a final preference questionnaire being administered once all tests had been completed. The order of respirator testing was randomly allocated.

Fig. 1. Ear loop clip used in face fit tests.

The fit testing was conducted in private rooms within the school premises, which were typically either first aid or unused classrooms. The approximate areas of the rooms were 20 and 34 m^2 in the private and public schools in Indonesia and 10 and 15 m^2 in the private and public schools in Nepal, respectively. In Indonesia, all windows were closed in both schools. In the private school, the air conditioning was on. In Nepal, windows were generally closed, however, in the private school, the windows were occasionally opened for a few minutes when a child felt hot or uncomfortable. Windows were closed at all times in the public school in Nepal. In this room, a ceiling fan was used at very low speed during the tests.

2.4. *Facial dimensions*

Facial dimensions of each subject were measured at the start of the study, prior to the first face fit test. Two facial dimensions of each child were measured: face width (Bizygomatic breadth) and face length (Menton-Sellion length) using sliding callipers (AnthroFlex Small Bone Anthropometer, with 140 mm range, resolution 1 mm), as illustrated in Supplementary Material 1. Tests were carried out by trained researchers of the same biological sex as the child.

2.5. *Fit testing*

Face fit testing was carried out using a TSI PortaCount™ Respirator Fit Tester 8048 which provides a quantitative assessment of face seal leakage. To perform a fit test, the PortaCount™ Respirator Fit Tester draws samples of air from inside and outside of the respirator whilst being worn. A sample probe was riveted into the inside of the respirator, typically off centre in the middle of the respirator, taking care to ensure that this did not press against the child's face or mouth when being worn. The tubing connecting the sampling probe on the respirator to the PortaCount™ Respirator Fit Tester was clipped to a lanyard (supplied by the study team) worn by the child, with the child holding the tubing, to ensure that the tubing did not pull the respirator off the child's face during the exercises.

The child was helped by the researchers to don the allocated respirator and to ensure the best fit possible (either with or without the additional ear loop clip) with the sampling tubes attached. For example, the respirator was fully opened, the nose clip (where present) was moulded to the child's face and the additional ear loop clip was placed in the best position for the child, which varied from the crown of the head to the lower head region. It should be noted that, where ear loop clips were worn with a hijab, the ear loops of the respirator were worn over the hijab, resulting in the respirator being in contact with the hijab rather than the skin at the sides, whereas the ear loops of the respirator were worn underneath the hijab when no additional ear loop clip was used. The respirator was sometimes in contact with the hijab in the chin region, both with and without the additional ear loop clip. Children were given a private space to remove the hijab to fit the respirator, if necessary. Care was taken to ensure that the tubing connected to the PortaCount™ Respirator Fit Tester did not pull or distort the respirator and therefore affect the fit. Once the child was happy that the respirator felt comfortable and no further adjustments were needed, the researcher took three photographs of the respirator being worn: both side views and a front view.

The test involved the generation of a non-harmful ambient saltwater aerosol using the particle generator supplied with the PortaCount™ Respirator Fit Tester equipment. The saltwater aerosol was used as the challenge agent, and the concentration of the challenge agent was measured outside (C_{out}) and inside (C_{in}) the respirator. The fit factor for each exercise (see below) was calculated as the ratio of C_{out} to C_{in}. An overall fit factor (hereafter referred to as "fit factor") was then calculated for the entire test by the PortaCount™ Respirator Fit Tester.

Prior to the onset of face fit testing, a sequence of daily checks was carried out to ensure that ambient conditions were appropriate (ambient concentrations $\geq$3000 particles/cm^3) and the equipment was working correctly. The face fit tests were not allowed to commence unless the daily checks were satisfactory. To note, the ambient concentration also included whatever particulate pollution was already in the room.

The US Occupational and Safety Health Administration (OSHA) approved '*Modified fit test protocol for filtering face piece respirators*' procedure was utilised (OSHA, 2019). This short test protocol (around 2 min in duration) includes key activities to test the fit of the respirator worn (these being in order, bending over, talking (counting numbers up/down), moving head side-to-side and up-and-down). This test schedule was considered appropriate for the target age group and allowed for all the face fit tests to be conducted within school time without significantly imposing on the child's learning. The researchers also ensured that the pace of each of the activities was as consistent as possible among children by demonstrating the speed at which the movements should be conducted. Each respirator was tested twice per child – once without the additional ear loop clip and once with it.

For half face respirators, OSHA considers a fit factor of 100 or greater to be a pass from an occupational, workplace setting, perspective (OSHA, 2019). A fit factor of 100 means the concentration of particles inside the respirator is 100 times less than those measured outside the respirator, i.e. there is a reduction in exposure of 99 %. A fit factor of 10 means that the concentration inside the respirator is 10 times less than those measured outside, i.e. there is a reduction in exposure of 90 %. The upper limit of quantification for the PortaCount™ Respirator Fit Tester is 200 and any value higher will be recorded as 201.

2.6. *Wearability questionnaires*

Administration of the questionnaires was researcher led, in the participant's local language, with the researcher recording the responses on behalf of the participant. Researchers endeavoured not to influence opinion – they did not help the children to think of answers or indicate that any answer was favourable. The English language version of the questionnaires is provided in Supplementary Material 1 (these were translated into the local language for use by the researchers). The questionnaires were developed based on insights gained from an earlier part of the FACE-UP project which explored children's knowledge of masks and their mask features preferences (Nila, Unpublished results).

After each face fit test, the children were asked to indicate their level of agreement (strongly agree, somewhat agree, neither agree or disagree, somewhat disagree, strongly disagree) with respect to whether: the respirator was comfortable on their face; the respirator made their face feel hot; it was easy to breathe when wearing the respirator; the respirator fitted their face well; they felt embarrassed when wearing the respirator; and they liked how the respirator looked. The answers were converted to a five-point Likert scale (−2, −1, 0, +1, +2) with a negative score representing disagreement, zero representing a neutral response, and a positive score representing agreement. For each respirator the children were also asked if they would wear it again.

After the six face fit tests were completed, a final questionnaire was administered. The children were asked if they preferred patterned or plain respirators (Nepal only), respirators with or without an additional ear loop clip, coloured or white respirators, and respirators with a horizontal or vertical fold.

It should be noted that in the questionnaires, “respirators” were referred to as “masks” as the children were more familiar with this term and all respirators tested had “mask” or “masker” (the term for mask in Bahasa Indonesia) in their name.

2.7. Data analysis

Questionnaire and facial measurement data were collected in Qualtrics (Qualtrics, Provo, UT), and exported for analysis using Stata 18.0 (StataCorp, College Station TX, USA). Data from the PortaCount™ Respirator Fit Tester was exported for cleaning in Microsoft Excel. The resulting Excel file was imported in Stata 18.0 for analysis.

Summary descriptive statistics, including mean, standard deviation (SD), median, minimum and maximum were generated for fit factor for each test. The proportion of fit factors >10 (i.e. concentration reduced by at least a factor of 10) and the proportion equal to 1, i.e. no protection, were also reported.

The association of fit factor with respirator was investigated using multilevel modelling. Fit factors for each country, separately, were log transformed to account for the higher (skewed right) values. The “best”, i.e. the respirator with the highest median fit factor, in each country was used as the reference for analysis. Participant was included as a random intercept to account for the testing of multiple respirators. The association with other factors: additional ear loop clip, age (years), sex, face width (mm), face length (mm), glasses, hijab (Indonesia only) were also considered. Age, face width and face length were continuous variables and the remaining variables were categorical. The respirator coefficients represent the contribution of the respirator to the fit factor. Pearson correlations were calculated between the variables in the model.

Descriptive statistics were calculated for each of the respirator wearability criteria. Pairwise comparisons of individual respirators were carried out to evaluate differences between each of the respirators using Dunnett’s test.

3. Results

3.1. Descriptive statistics

The characteristics of the 60 children are summarised in Table 2. All children successfully completed each of their six face fit tests (three respirators, each with and without an additional ear loop clip) and accompanying questionnaires. A good balance between male and female children was achieved in the study. In Indonesia, where older children were preferentially recruited, the children were mostly in the age range of 9–11 years whereas in Nepal the children were evenly spread within the age range of 7–12 years.

3.2. Fit of respirators to children’s faces, with and without additional clip

Face sizes were similar in both countries (Fig. 2), with mean (SD) length 94 (6.0) mm and 93 (5.9) mm and width 116 (8.3) mm and 110 (8.1) mm in Indonesia and Nepal, respectively. Four face sizes in Indonesia and one in Nepal are considered adult sized faces according to ISO, (2022). Further details on face size can be found in Supplementary Material 2.

Table 2
Description of participants – sex, age and socioeconomic range.

	Indonesia		Nepal	
	N	%	N	%
Sex				
Male	15	50	14	47
Female	15	50	16	53
Age at time of face fit test (years)				
7	0	0	6	20
8	0	0	4	13
9	6	20	5	17
10	9	30	4	13
11	13	43	5	17
12	1	3	6	20
13	1	3	0	0
Socioeconomic range[a]				
Public school, low to middle	16	53		
Public school, mixed			18	60
Private school, middle to high	14	47	12	40

[a] Information on socioeconomic range of students provided by each school.

Fit factors for the respirators tested are presented in Table 3. Most fit factors were less than 10, i.e. a reduction in exposure of <90 %. Median and interquartile range (IQR) fit factors for the Indonesian respirators Pokana and Fit-U Mask were 1 (1–2), even when the additional ear loop clip was used, indicating that the respirators provided no protection. Similarly, in Nepal, median (IQR) fit factors for Jinjiang and Purvigor were 1 (1–2) without the additional ear loop clip. However, when the additional ear loop clip was used the median (IQR) fit factor for both respirators increased to 2 (2–3) and 2 (1–2), respectively, i.e. a reduction in exposure of 50 %. The respirator with the highest median (IQR) fit factor in Indonesia was Oncare, which had a fit factor of 3 (2–3), a 67 % reduction in exposure, without the additional ear loop clip compared to 4 (2–6), a 75 % reduction in exposure, with the clip. In Nepal, Double A Care had the highest median (IQR) fit factors: 2 (1–4), a 50 % reduction in exposure, without the additional ear loop clip and 4 (2–7), a 75 % reduction in exposure with the clip.

In Indonesia there were five tests (out of 180, 3 %) where the fit factor was greater than 10 and these were all when the additional ear loop clip was worn with the respirator: four occasions when wearing Oncare and once when wearing Fit-U Mask. In Nepal, there were 10 occasions (out of 180, 6 %) where the fit factor was greater than 10: two when wearing Jinjiang with the additional ear loop clip and eight when wearing Double A Care, two without the additional ear loop clip and four with the clip. As also reflected in the medians, the respirators with the highest fit factors were Oncare and Double A Care in Indonesia and Nepal, respectively. These respirators are the only ones with a horizontal fold that were tested in each country.

As mentioned, fit factors were generally higher when wearing the respirator with the additional ear loop clip, especially for respirators Oncare in Indonesia and Double A Care in Nepal. Particularly striking is the number of instances where the fit factor was equal to 1, i.e. no protection provided, for respirator Pokana (93 %) and Fit-U Mask (73 %) in Indonesia and respirators Jinjiang (60 %) and Purvigor (60 %) in Nepal. Use of the additional ear loop clip reduced the number of tests with a fit factor of 1, particularly for the ‘best’ respirators, Oncare in Indonesia and Double A Care in Nepal, which both had a horizontal fold, thereby indicating at least some improvement in protection in most cases.

For children who wore glasses, they were not always consistently worn for all six tests. In Indonesia, only one child wore glasses and only on one of the two test days. Similarly, in Nepal, five children wore glasses, two on both test days and three only on one of the two test days. In Indonesia, most girls (10, 67 %) wore hijabs for all six tests. One girl did not wear a hijab for any of the tests. The remaining four (27 %) girls wore hijabs for three out of six tests, i.e. on one of the test days but not the other. The reason for this was that hijabs did not have to be worn on

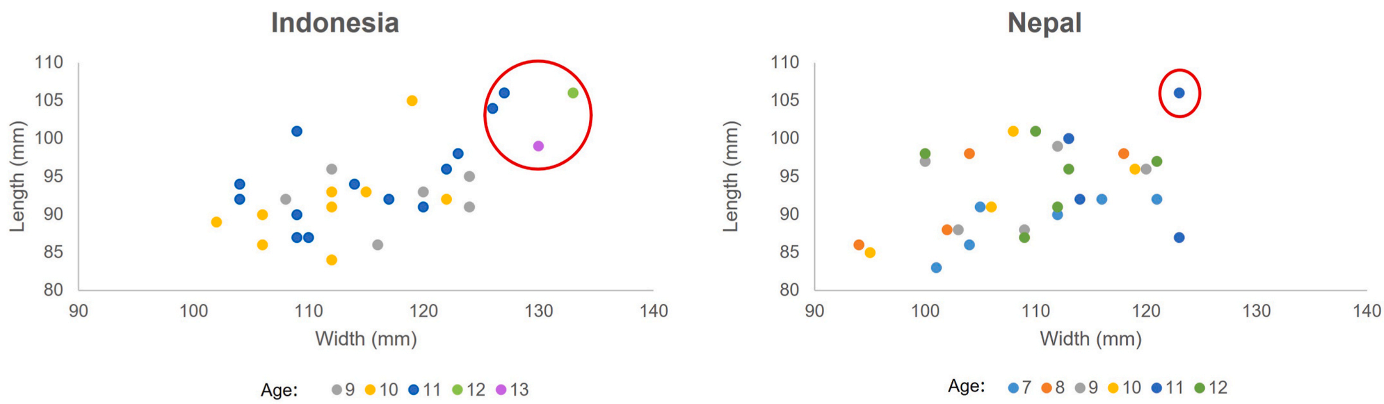

Fig. 2. Face length and width for each study participant by age. Coloured dots represent the age of each child and red ellipses denote those considered adult sized according to ISO (2022). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3
Summary of fit factors for the respirators tested, with and without additional ear loop clip.

Mask	No additional ear loop clip						With additional ear loop clip					
Mask	Mean (SD)	Median (IQR)	Min	Max	No. (%)		Mean (SD)	Median (IQR)	Min	Max	No. (%)	
					FF > 10	FF = 1					FF > 10	FF = 1
Indonesia												
Oncare	3.2 (1.6)	3 (2–3)	1	9	0 (0)	1 (3)	12.6 (36.1)	4 (2–6)	2	201	4 (13)	0 (0)
Pokana	1.1 (0.3)	1 (1–1)	1	2	0 (0)	28 (93)	1.4 (0.6)	1 (1–2)	1	3	0 (0)	20 (67)
Fit-U Mask	1.3 (0.4)	1 (1–2)	1	2	0 (0)	22 (73)	6.4 (26.6)	1 (1–2)	1	147	1 (3)	19 (63)
Nepal												
Jinjiang	2.1 (2.0)	1 (1–2)	1	9	0 (0)	18 (60)	3.3 (3.4)	2 (2–3)	1	14	2 (7)	6 (20)
Purvigor	1.5 (0.7)	1 (1–2)	1	4	0 (0)	18 (60)	1.8 (1.0)	2 (1–2)	1	5	0 (0)	13 (43)
Double A Care	4.1 (6.1)	2 (1–4)	1	26	2 (6)	8 (27)	7.4 (8.5)	4 (2–7)	1	33	6 (20)	2 (7)

days when the girls had scouts or sports classes. All girls who entered the test room wearing a hijab were tested wearing their hijab.

There were only two instances where the fit factor was greater than 100 (this being the value considered a pass from an occupational perspective for an N95 respirator), both in Indonesia and both for the same child, a girl aged 9 who was wearing a hijab. These were for respirators Oncare (fit factor = 201) and Fit-U Mask (fit factor = 147) and both were worn with the additional ear loop clip. Fig. 3 shows the female child wearing the respirators Oncare (left hand image) and Fit-U Mask (right hand image) with the additional ear loop clip over her hijab.

Fig. 4 shows an example of a poorly fitting respirator (Purvigor). This respirator, whilst marketed as having a nose clip, did not and it was evident that there was a gap at the nose, as well as under the chin and at the cheekbones. Overall, the respirator was too big for the child’s face and achieving a good fit would be very unlikely.

3.3. Multilevel regression model

The results of the multilevel regression modelling are shown in Fig. 5. It should be noted that the graphs indicate a change in fit factor,

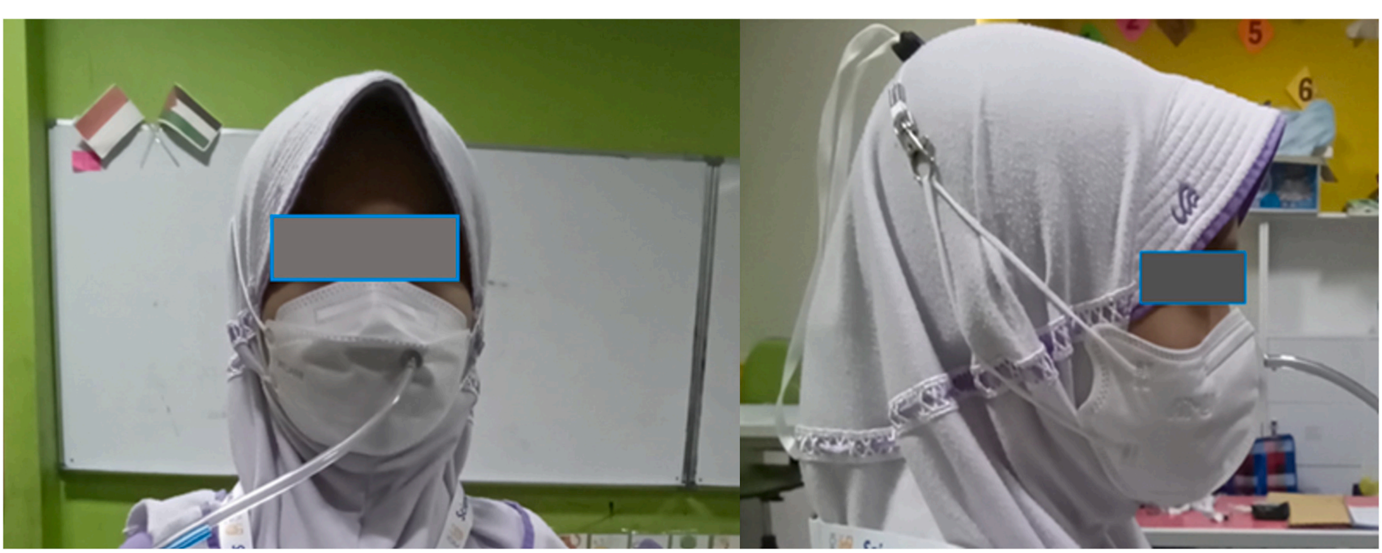

Fig. 3. Oncare (left hand image) and Fit-U Mask (right hand image) onchild with the highest fit factors.

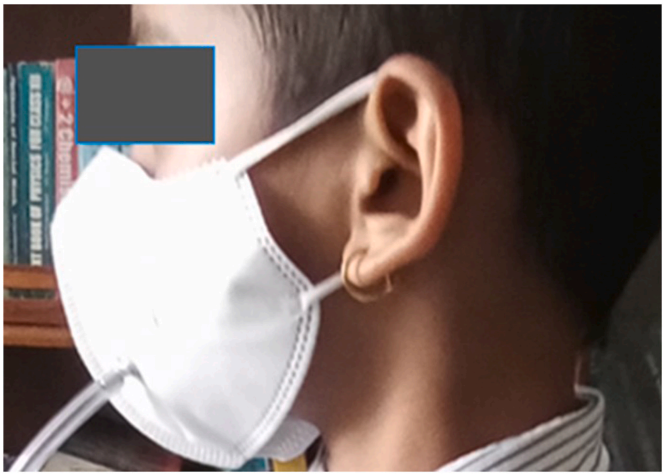

Fig. 4. Example of poorly fitting respirator, Purvigor.

not exposure, with a negative percentage indicating a reduction in log fit factor and hence an increase in exposure for a particular variable. In both countries correlations across all variables were weak (<0.4) except for face width and face length ($r = 0.61$ in Indonesia and $r = 0.43$ in Nepal). In Indonesia, respirators Pokana and Fit-U Mask, were associated with decreases in log fit factor of 70 %, (95 % confidence interval (CI) 63–75 %) and 65 % (95 % CI 57–71 %) respectively, compared with respirator Oncare. In Nepal, respirators Jinjiang and Purvigor, were associated with decreases in log fit factor of 41 % (95 % 28–51 %) and 56 % (95 % 47–64 %) respectively, compared with respirator Double A Care. Use of the additional ear loop clip was associated with increases in log fit factor of 42 % (95 % 20–67 %) and 50 % (95 % CI 29–75 %) for Indonesian and Nepalese respirators, respectively.

In Indonesia, face length was associated with an increase in fit factor of 2.9 % (95 % 0.4–5.5 %) i.e. each mm increase in face length leads to a 2.9 % increase in log fit factor. There were no strong associations between log fit factor and face width, biological sex, wearing glasses, wearing a hijab or age, i.e. the 95 % CIs included 0. In Nepal, wearing glasses was associated with an increase in fit factor of 74 % (95 % CI 24–143 %) and a very slight increase in fit factor of 3.9 % (95 % CI 2.1–5.7 %) with face width i.e. each mm increase in face fit leads to a 3.9 % increase in log fit factor. There were no clear associations between fit factor and face length, biological sex or age.

3.4. Respirator wearability ratings

Mean scores for each respirator and perception, recorded after each fit test, are shown in Table 4. Mean scores for the respirator being comfortable on the child's face were positive for all respirators, with or without the additional ear loop clip, in both countries. The highest mean score was 1.1 for the Fit-U Mask with clip in Indonesia and 1.6 for Double A Care with clip in Nepal. In Indonesia the mean scores were negative for hotness, ranging from −1.0 to −0.7, indicating that they did not make their faces feel hot. In Nepal, mean scores were positive for Jinjiang and Double A Care, for hotness, ranging from 0.1 to 0.3, indicating that the respirators made their faces feel hot. However, for Purvigor, there was a mean score of 0.0 without the clip, i.e. their faces did not feel either hot or cold, whereas when the clip was worn with the respirator, the mean score was negative, i.e. the respirator did not make their face feel hot.

In both countries, and for all respirator combinations, children indicated that it was easy to breathe with the respirator on, with mean scores ranging from 0.3 to 1.7. With one exception, mean scores for fit were positive (0.1–1.4), indicating that the children felt the respirators fitted their faces. The one exception was in Nepal for the fit of Jinjiang without the additional ear loop clip, where the mean score was 0.0, indicating a neutral response. In both countries the mean score for perception of fit increased when the additional ear loop clip was worn. The exception to this was in Indonesia, for Fit-U Mask, where the mean score wearing the ear loop clip was less than when not wearing the clip.

The mean scores for embarrassment were all negative, ranging from −1.4 to −0.9, indicating that the children did not feel embarrassed when wearing any of the respirators. Mean scores for liking how the respirators looked were all positive, ranging from 0.9 to 1.6. There were no significant differences in any of the perceptions: comfort, hotness, breathability, fit, embarrassment or liking how they looked among respirators for either country. Correlations between fit factor and how the children felt the respirators fitted their faces were weak (0.19 in Indonesia and 0.33 in Nepal.

After each respirator was tested, the children were asked if they would wear that respirator again (Fig. 6). Percentages were very similar in Indonesia ranging from 50 % saying they would wear Pokana with the additional ear loop clip to 63 % saying they would wear Oncare with the clip again. In Nepal the response was more positive with percentages ranging from 77 % for Jiniang without the additional ear loop clip to 93 % for Purvigor without the clip. There was no obvious preference for wearing a respirator with or without the additional ear loop clip.

After all the tests were completed, the children were asked which respirators they preferred with respect to certain style characteristics:

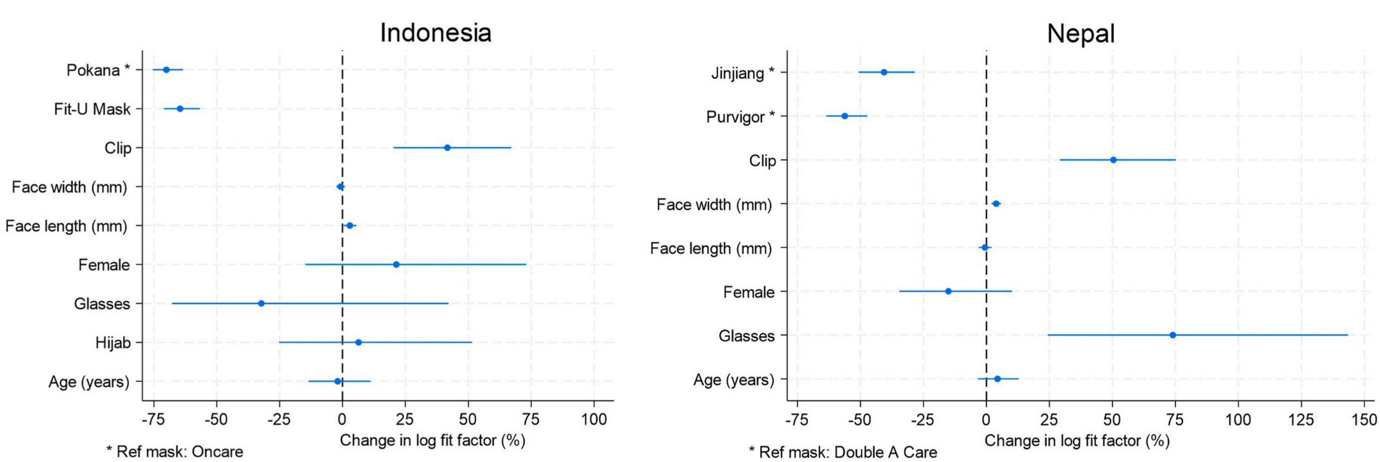

Fig. 5. Plot of regression coefficients as percentage change in log fit factor for Indonesia and Nepal. The reference respirators were Oncare in Indonesia and Double A Care in Nepal. Error bars are 95 % confidence intervals. Models were adjusted for all variables presented. References are without additional ear loop clip for clip, male for female, not wearing glasses for glasses and not wearing hijab for hijab.

Table 4
Mean (SD) scores (range = −2 (strongly disagree) to +2 (strongly agree)) for each respirator and wearability criterion.

Criteria	Indonesia						Nepal					
	Oncare		Pokana		Fit-U Mask		Jinjiang		Purvigor		Double A Care	
	No clip[c]	Clip	No clip	Clip	No clip	Clip	No clip	Clip	No clip	Clip	No clip	Clip
Comfort[a]	0.9 (0.9)	1.0 (0.8)	0.7 (0.9)	0.9 (0.7)	1.0 (0.7)	1.1 (0.8)	1.2 (1.2)	1.4 (0.9)	1.3 (1.0)	1.2 (1.2)	1.3 (1.1)	1.6 (0.7)
Hotness[b]	−1.0 (0)	−0.7 (0.8)	−0.7 (0.8)	−0.9 (0.8)	−1.0 (0.7)	−0.9 (0.8)	0.2 (1.4)	0.2 (1.5)	0 (1.7)	−0.2 (1.4)	0.3 (1.7)	0.1 (1.5)
Breathability[a]	0.7 (0.8)	0.4 (0.9)	0.4 (1.0)	0.5 (0.8)	0.6 (0.9)	0.3 (0.9)	1.3 (1.0)	1.2 (1.1)	1.5 (0.7)	1.7 (0.7)	1.5 (0.7)	1.5 (0.9)
Fit[a]	0.5 (0.9)	0.7 (1.2)	0.1 (1.0)	0.5 (0.9)	0.8 (1.0)	0.6 (1.0)	0 (1.5)	1.0 (1.4)	0.2 (1.5)	0.9 (1.3)	0.6 (1.4)	1.4 (0.9)
Embarrassed[b]	−0.9 (0.8)	−0.8 (0.9)	−0.9 (0.8)	−1.1 (0.8)	−0.9 (0.9)	−0.6 (1.0)	−1.4 (1.0)	−1.4 (1.0)	−1.4 (1.0)	−1.1 (1.2)	−1.4 (1.1)	−1.2 (1.3)
Like[a]	1.0 (0.8)	0.9 (0.9)	0.9 (0.8)	0.9 (0.8)	1.1 (0.7)	0.9 (0.9)	1.6 (0.7)	1.4 (1.0)	1.4 (0.8)	1.4 (1.0)	1.4 (0.8)	1.4 (0.9)

[a] a positive score for comfort, breathability, fit and like means that the child found the respirator comfortable on the face, it was easy to breathe, it fitted them well and they liked how the respirator looked, respectively.
[b] a positive score for hotness and embarrassed means that the child felt the respirator made their face feel hot and that they felt embarrassed wearing the respirator, respectively.
[c] clip in all instances refers to the additional ear loop clip.

use of additional ear loop clip, colour of respirator, if respirator was patterned or plain, and shape of respirator (horizontal or vertical fold). Results are presented in Table 5.

In Indonesia there was a slight preference for wearing respirators without the additional ear loop clip (50 % compared with 47 %)), whereas in Nepal there was a preference for wearing the respirators with the clip (57 % compared with 37 %). In both countries there was a clear preference for coloured respirators compared with white respirators: 57 % in Indonesia and 60 % in Nepal. Most of the participants in Nepal preferred patterned respirators (there were no patterned respirators tested in Indonesia). In both countries most children indicated that they preferred respirators with a vertical fold rather than respirators with a horizontal fold (63 % and 53 % in Indonesia and Nepal respectively). Further details relating to wearability can be found in Supplementary Material 3.

4. Discussion

The purpose of this study was to determine how well locally available respirators marketed for children in Indonesia and Nepal fitted their faces and to determine how the use of an additional ear loop clip affected the fit. The wearability and style preferences of the tested respirators were also assessed.

4.1. Fit of the tested respirators

Although all respirators were independently verified as passing N95 filtration efficiency tests, fit factors were generally less than 10, i.e. <90 % reduction in exposure, which can be attributed to poor fit due to the respirators being too large for the children's faces. However, even a fit factor of 2 will lead to a 50 % reduction in exposure. In both countries, the best fitting respirators had horizontal folds and provided significantly more protection than the other two respirators in each country, which had vertical folds. However, horizontal fold respirators are less commonly available in both countries. The use of an additional ear loop clip significantly improved respirator fit in both countries. Other studies have also reported that the fit of a respirator or mask can be improved by modification or alteration (Steinle et al., 2018; O'Kelly et al., (2022); Niu et al., 2023).

In Nepal, the Purvigor respirator was missing the nose clip, meaning that fit around the nose cannot be achieved, as illustrated in Fig. 4. Higher fit factors may have been possible had the nose clip been in place and used correctly. Users and carers should be diligent in checking products to ensure all components are present and return to the point of purchase if not. There is also a need for provision of information to carers so that they are aware of what they should consider and check for when purchasing respirators for their children, as well as how to best fit a respirator to their child's face.

It is evident from the study that some of the respirators used, although specifically marketed for children, clearly did not fit the children, because they were too large. It is unlikely that these respirators were designed specifically for the facial characteristics for the two different populations studied although they were available for purchase in these locations. This is possibly because neither country has its own respirator standards (for adults or children) and most of the respirators were not manufactured in the countries where they were purchased. Several studies representing different adult populations (Yu et al., 2014; (China) Fakherpour et al., 2021 (Iran); Khairul Hasni et al., 2023 (Malaysia)) and two recent systematic reviews, (Fakherpour et al., 2023; Chopra et al., 2021), have highlighted the importance of selecting respirators which fit the facial characteristics of the population. A recent study by Baxter et al. (2024) compared eight different KN95 style respirators with ear loop straps in 29 adults of Western European origin and reported that only one of the 232 tests carried out achieved a fit factor above 100.

On only two occasions was a fit factor greater than 100 achieved,

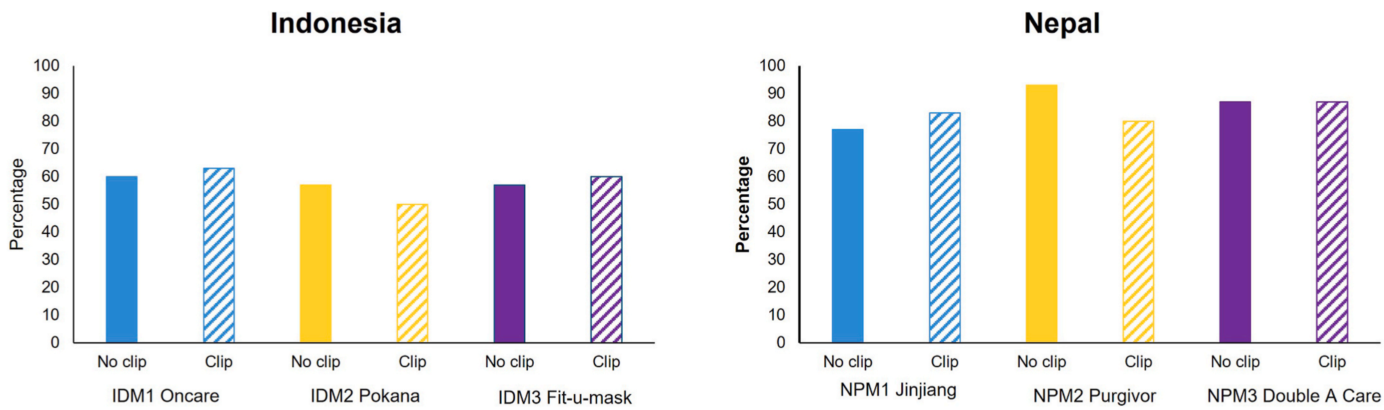

Fig. 6. Percentage of children who would wear each respirator again.

Table 5
Number (%) of children preferring certain styles.

Style	Indonesia	Nepal
Additional ear loop clip		
Yes	14 (47)	17 (57)
No	15 (50)	11 (37)
Don't mind	1 (3)	2 (7)
Colour		
White	11 (37)	11 (37)
Coloured	17 (57)	18 (60)
Don't mind	2 (7)	1 (3)
Pattern		
Yes	–	18 (60)
No	–	10 (33)
Don't mind	–	2 (7)
Fold		
Horizontal	8 (27)	13 (43)
Vertical	19 (63)	16 (53)
Don't mind	3 (10)	1 (3)

both times in Indonesia, on the same child, when the additional ear loop clip was used. This may have been more to do with the fact that, in each instance, the child was wearing a hijab, and this may have helped provide a seal between the respirator and the face. It is clear from many of the photographs that the respirators were too large for the children and there were large gaps at the nose, chin and sides, despite the researchers ensuring that the respirators fitted as well as possible before testing. In real-life situations where it is clearly apparent 'visually' that the respirator is too big (or small) for the child, then steps should be taken to find an alternative respirator which is a more appropriate size.

A fit factor of >100, i.e. a reduction in exposure of >99 %, is an OSHA standard for workplaces (OSHA, 2019). However, it is unrealistic and unnecessary to expect such a fit factor in the general population. There appears to be no published information on a suitable fit factor in ambient situations e.g., during periods of high air pollution. Overall, most fit factors were less than 10, i.e. less than 90 % reduction in exposure, even when the additional ear loop clip was used. Nevertheless, even a reduction in exposure of 50 % (fit factor of 2) represents a substantial change in the amount of particulate pollution that a child would be inhaling and introduces the ethical question of whether recommending some respiratory protection intervention is better than no intervention, even if it is not entirely effective (McDonald et al., 2020).

Current WHO guidelines state that annual average concentrations of $PM_{2.5}$ should not exceed 5 μg/m^3 and a 24 h mean concentration of 15 μg/m^3 (WHO, 2021). Carson, (Unpublished results) report week-long personal exposure monitoring of $PM_{2.5}$ for children in Bandung, Indonesia and Kathmandu, Nepal. The mean (median) 24-h $PM_{2.5}$ concentration in Bandung was 48.0 (41.0) μg/m^3 (10th May to June 4, 2023, end of the wet season and start of the dry season). In Kathmandu the mean (median) 24-h concentration was 45.8 (38.2) μg/m^3 (17th March to June 14, 2023, overlapping with the start of monsoon season). The concentrations are substantially above the WHO guideline values. In an (albeit unrealistic) scenario where respirators are always worn and concentrations are the same throughout the year, a fit factor of 10, i.e. a reduction in exposure of 90 %, would reduce exposure to less than 5 μg/m^3 in both countries, a suitable level when compared with the WHO guidelines. Even in the home, where children spend most of their time, reported concentrations were well above the WHO guidelines, with means (medians) of 48.9 (41.0) and 49.1 (39.3) μg/m^3 being reported by Carson, (Unpublished results) in Indonesia and Nepal, respectively. It is, of course, unrealistic to expect or assume that respirators will be always worn or that they will be worn in the home, but the calculation serves to illustrate the utility of respirators that fit far less well than the industry guidelines, in public settings. Nevertheless, it is also clear that personal interventions, such as respirators, are not sufficient to protect children entirely.

It is therefore imperative that priority is given to the implementation of effective control measures, which reduce particulate matter exposure at both regional and local levels. Ideally, emission sources should be removed or reduced, however, this is generally not feasible and impractical. Other interventions include the use of air purifiers to reduce household exposure and a review of the literature by Allen and Barn (2020) found that there was substantial evidence that HEPA air filters reduce indoor $PM_{2.5}$ concentrations and improve subclinical cardiopulmonary health indicators. However, air purifiers can only function in sealed indoor spaces and, in tropical countries such as Indonesia, closing windows, doors and other ventilation gaps is not feasible unless there is air conditioning to cool the room (which is rare in both homes and schools). In Nepal, governmental guidance is to keep windows and doors open during cooking to improve indoor air quality (Ministry of EnvironmentScience and Technology, 2009). Therefore, air purifiers are not a feasible intervention in much of the world (including many low-to-middle income nations).

Except for Goh et al. (2019), no fit test studies were identified which used masks specifically designed for children. Their study illustrated that it is possible to achieve a good fit with a respirator (with head straps rather than ear loops) specifically developed for children aged 7–14 years. van der Sande et al. (2008) showed that children were significantly less well protected than adults when using the same mask, which was unsurprising since children have smaller faces, and the masks were not designed for their faces. Jung et al. (2014) reported that the children's masks used in their study appeared to be adult masks that were reduced in size and given that breathing volume, pattern and rate are different in children, they questioned if a reduction in size, alone, is a suitable strategy for ensuring protection of children. Preliminary results reported by a large respirator manufacturer in the USA (conference call cited in Holm et al. (2021)) suggest that use of a small-sized adult N95 respirator by school age children may be expected to reduce exposure by around 80 % (corresponding to a fit factor of at least 5) for nearly all children. Their data suggested that the face sizes of many adolescents (age not stated) fall into the adult range of face sizes for which N95 respirators are tested. In this study, the children were pre-adolescent and according to the ISO, (2022) standard, four of the children (13 %) in Indonesia and one (3 %) in Nepal have face sizes than would be considered a small adult sized face, showing that, for pre-adolescent children, it is not possible to achieve such high rates of fit as reported by the above manufacturer.

4.2. Wearability and style preferences

Children were generally favourable about the respirators for all criteria: comfort, hotness, breathability, fit, embarrassment and liking how the mask looked. The exceptions were the Jinjiang and Double A Care respirators in Nepal, irrespective of whether or not the ear loop was worn, which the children found made their face hot. There were no significant differences between respirators for any of these criteria. Since the respirators did not fit the children well in many cases, then this may have influenced how the children rated the respirators, particularly with respect to comfort, hotness and breathability. However, the children were also positive about the respirators' fit, indicating that they do not understand what a good fit is. Kelly et al. (2021) noted that adult participants in their study were unable to reliably predict whether respirators fitted properly, routinely believing that poor-fitting respirators fitted well.

Although children in Indonesia preferred wearing respirators without the additional ear loop clip, children in Nepal preferred wearing respirators with the additional ear loop clip. This is in the context of children in Nepal not being used to wearing or seeing others wearing an additional ear loop clip as their use is not common whereas, in Indonesia, both hijab-wearing adults and children commonly use an additional ear loop clip when wearing a respirator. Children preferred coloured and patterned respirators (Nepal only), indicating that the appearance of the respirator is important to them. Studies by Smart et al. (2020) and Preest et al. (2024) have also found that appearance of a respirator is important to children. Le et al. (2023) reported that children were concerned with public perception of their appearance while wearing a respirator.

Children in both countries preferred respirators with vertical folds even though, based on fit factor, respirators with a horizontal fold fitted them better. Their preference may have been influenced by their preference for coloured and patterned respirators (which are commonly vertical fold) but, also, because vertical-fold respirators are much more prevalent in both countries, so the children are used to wearing/seeing them. Similarly, there was no association between fit factor and liking a respirator, which again emphasises the importance of appearance to the children.

5. Limitations

This study has several limitations. Firstly, only three types of respirators were chosen in each country and, as such, the level of fit and wearability measured only apply to these specific respirators. The study was set up to test the fit of specific masks rather than assess associations with individual characteristics, so it may have been underpowered; nevertheless, we were still able to identify some statistically significant associations. The analyses provided a quantitative/objective way to compare masks beyond the summary statistics and also to examine specific characteristics that are associated with fit.

The respirators were only worn for a short period of time, and it is likely that fit will decrease over time as the elastic components of the respirator tend to loosen with time. It is also likely that the fit of respirators would be challenged more during real-life wearing conditions where they are typically worn, not only for longer time periods, but also during a range of activities. van der Sande et al. (2008) reported a large decrease in penetration factor at the end of a 3-h test compared with the start of the test involving adult participants.

It is likely that actual fit by children in real-life situations will be lower due to lack of attention in ensuring a good fit when donning the respirator and ensuring the nose clip (when present) is correctly adjusted. It is also likely that children will adjust their respirators when wearing or removing and replacing them, which will also influence the actual fit. Testing was carried out during short, low breathing intensity activities and different results may be obtained both for fit and for wearability when playing or carrying out other, more intense, activities. In Indonesia, the study was conducted between July and September 2023, which was still within the dry season and in Nepal between August and October 2023, which was the end of the monsoon season and post-monsoon season. It is possible that other responses, in particular relating to wearability, may have occurred in different seasons which are hotter and have different humidity. Hu et al. (2022) demonstrated that prolonged respirator wearing increases participants' hot feelings, especially in warm environments.

It is possible that the responses to the wearability questions could have been influenced by the presence of the researchers, with children providing the answers which they thought the researchers wanted to hear, i.e. social desirability bias (King and Bruner, 2000; Miller et al., 2015). However, some of the comments provided by the children as to whether they would wear a particular respirator again indicate that this was not the case. For example, one child commented that they would wear the mask again because it was the "same as dad's" and another child commented that they would not wear the mask again because they did "not like the pattern and colour" of the mask (see Supplementary Material 3, for a summary of comments). Since this group of children had agreed to participate in the respirator study, they may have been more enthusiastic about respirator wearing than the general population of children.

Although the results presented in this manuscript cannot be considered representative of all respirators that may be available for use by children to protect them against particulate air pollution, they do provide some useful insights into how well such respirators fit and points to consider when encouraging the use of such interventions by children.

6. Conclusions

This study is one of the first to measure the fit of respirators marketed for children. While fit factors were low compared to occupational regulations, for some respirators, the results represent a substantial potential reduction in exposure to particulate pollution for children, if fitted properly. The results highlight that there is a need for respirators to be designed to suit the specific facial dimensions of children. Although high filtration is critical, it isn't sufficient if the respirator does not fit. This study also illustrates that modification, in this case by use of an additional ear loop clip, can result in a statistically significant improvement in the fit of a respirator. It is also important that carers and children understand the characteristics of a good fit, what to look for and what they need to do to ensure a good fit.The FACE-UP project has addressed this by producing a short video for children and a booklet for parents, which will be available in the Children's Environmental Health Collaborative's Knowledge Library (UNICEF, 2025).

CRediT authorship contribution statement

Anne Sleeuwenhoek: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Claire J. Horwell:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Kusum Shahi:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation. **Jihan Nur Azizah:** Writing – review &

editing, Writing – original draft, Methodology, Investigation, Data curation. **Rabindra Bhandari:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation. **William Mueller:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis. **Muhammad Iqbal:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Data curation. **Meghnath Dhimal:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Miranda Loh:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Conceptualization. **Karen S. Galea:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

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Conflict of interest

The authors declare that they have no actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, this work.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijheh.2025.114561.

Data availability

The datasets used for this study have been anonymised to protect the identity of individuals and uploaded to the Open Science Framework (https://doi.org/10.17605/OSF.IO/FBD8E).

References

Allen, R.W., Barn, P., 2020. Individual- and household-level interventions to reduce air pollution exposures and health risks: a review of the recent literature. Curr. Environ. Health Rep 7, 424–440. https://doi.org/10.1007/s40572-020-00296-z.

Baxter, N., Beattie, H., Nicholls, G., Smith, D., 2024. Fit testing of respirators with ear loop straps. J. Int. Soc. Respir. Prot. 41, 57–66.

Carson, F., Horwell, C., Iqbal, M., Shahi, K., Bhandari, R., Sofyan, A., Santoso, D., Oginawati, K., Mueller, W., Dhimal, M., Loh, M., Galea, K.S., Unpublished results. Assessment of PM2.5 Exposure Experienced by Children Living in Bandung, Indonesia and Kathmandu. Nepal. (Submitted to Int J Hyg Environ Health).

Chopra, J., Abiakam, N., Kim, H., Metcalf, C., Worsley, P., Cheong, Y., 2021. The influence of gender and ethnicity on facemasks and respiratory protective equipment fit: a systematic review and meta-analysis. BMJ Glob. Health 6, e005537. https://doi.org/10.1136/bmjgh-2021-005537.

Fakherpour, A., Jahangiri, M., Seif, M., Charkhand, H., Abbaspour, S., Floyd, E.L., 2021. Quantitative fit testing of filtering face-piece respirators during the COVID-19 pandemic reveals anthropometric deficits in most respirators available in Iran. J. Environ. Health Sci. 19, 805–817. https://doi.org/10.1007/s40201-021-00648-3.

Fakherpour, A., Jahangiri, M., Jansz, J., 2023. A systematic review of passing fit testing of the masks and respirators used during the COVID-19 pandemic: Part 1-quantitative fit test procedures. PLoS One 18, e0293129. https://doi.org/10.1371/journal.pone.0293129.

Goh, D.Y.T., Mun, M.W., Lee, W.L.J., Teoh, O.H., Rajgor, D.D., 2019. A randomised clinical trial to evaluate the safety, fit, comfort of a novel N95 mask in children. Sci. Rep. 12, 18952. https://doi.org/10.1038/s41598-019-55451-w.

Greenhalgh, T., Schmid, M.B., Czypionka, T., Bassler, D., Gruer, L., 2020. Face masks for the public during the covid-19 crisis. Br. Med. J. 369, m1435. https://doi.org/10.1136/bmj.m1435.

Greenhalgh, T., MacIntyre, C.R., Baker, M.G., Bhattacharjee, S., Chughtai, A.A., Fisman, D., Kunasekaran, M., Kvalsvig, A., Lupton, D., Oliver, M., Tawfiq, E., Ungrin, M., Vipond, J., 2024. Masks and respirators for prevention of respiratory infections: a state of the science review. Clin. Microbiol. Rev. 37. https://doi.org/10.1128/cmr.00124-23.

Gudgin Dickson, E.F., Tredinnick-Higgins, J.L., Horwell, C.J., Galea, K.S., Loh, M. Unpublished results. Factors Affecting Childhood Exposure to Urban Particulates (FACE-UP): Particulate Penetration and Pressure Drop Testing of Candidate Child-Sized Respirators to Reduce Exposure. (Submitted to J. Int. Soc. Respir. Prot.).

Holm, S.M., Miller, M.D., Balmes, J.R., 2021. Health effects of wildfire smoke in children and public health tools: a narrative review. J. Expo. Sci. Environ. Epidemiol. 31, 1–20. https://doi.org/10.1038/s41370-020-00267-4.

Horwell, C.J., Ferdiwijaya, D., Wahyudi, T., L Dominelli, L., 2019. Use of respiratory protection in Yogyakarta during the 2014 eruption of Kelud, Indonesia: community and agency perspectives. J. Volcanol. Geoth. Res. 382, 92–102. https://doi.org/10.1016/j.jvolgeores.2017.06.004.

Hu, R., Liu, J., Xie, Y., Jiao, J., Fang, Z., Lin, B., 2022. Effects of mask wearing duration and relative humidity on thermal perception in the summer outdoor built environment. Build. Simulat. 16, 1601–1616. https://doi.org/10.1007/s12273-022-0978-9. Epub ahead of print.

HEI, 2024. State of Global Air 2024. Special Report. https://www.healtheffects.org/announcements/new-state-global-air-report-finds-air-pollution-second-leading-risk-factor-death (accessed 20 March 2025).

ISO 16976-2, 2022. Respiratory protective devices. Human factors – Part 2: Anthropometrics. Edition 1, pg. 1-25. International Organization for Standardization.

Jung, H., Kim, J.K., Lee, S., Lee, J., Kim, J., Tsai, P., Yoon, C., 2014. Comparison of filtration efficiency and pressure drop in anti-yellow sand masks, quarantine masks, medical masks, general masks, and handkerchiefs. Aerosol Air Qual. Res. 14, 991–1002. https://doi.org/10.4209/aaqr.2013.06.0201.

Khairul Hasni, N.A., Ismail, R., Muhamad Robat, R., Mohamad, N., Suib, F.A., Pahrol, M. A., Mahmud, H., Osman, B., Lim, Y.C., Seman, Z., Shaharudin, R., 2023. The effect of N95 designs on respirator fit and its associations with gender and facial dimensions. PLoS One 18, e0288105. https://doi.org/10.1371/journal.pone.0288105.

King, M.F., Bruner, G.C., 2000. Social desirability bias: a neglected aspect of validity testing. Psychol. Market. 17, 79–103. https://doi.org/10.1002/(SICI)1520-6793(200002)17:2<79::AID-MAR2>3.0.CO;2-0.

Le, H.H.T.C., Vien, N.T., Dang, T.N., Ware, R.S., Phung, D., Thai, P.K., Ranganathan, S., Vinh, N.N., Dung, P.H.T., Thanh, H.N., Dung, T.T.T., Hien, T.T., Sly, P.D., Le An, P., 2023. Wearing masks as a protective measure for children against traffic-related air pollution: a comparison of perceptions between school children and their caregivers in Ho Chi Minh City, Vietnam. Trop. Med. Int. Health 28, 753–762. https://doi.org/10.1111/tmi.13923.

Lelieveld, J., Haines, A., Burnett, R., Tonne, C., Klingmüller, K., Münzel, T., Pozzer, A., 2023. Air pollution deaths attributable to fossil fuels: observational and modelling study. Br. Med. J. 383, e077784. https://doi.org/10.1136/bmj-2023-077784.

McDonald, F., Horwell, C.J., Wecker, R., Dominelli, L., Loh, M., Kamanyire, R., Ugarte, C., 2020. Facemask use for community protection from air pollution disasters: an ethical overview and framework to guide agency decision making. Int. J. Disaster Risk Sci. 43, 101376. https://doi.org/10.1016/j.ijdrr.2019.101376.

Miller, P.H., Baxter, S.D., Royer, J.A., Hitchcock, D.B., Smith, A.F., Collins, K.L., Guinn, C.H., Smith, A.L., Puryear, M.P., Vaadi, K.K., Finney, C.J., 2015. Children's social desirability: effects of test assessment mode. Pers. Indiv. Differ. 83, 85–90. https://doi.org/10.1016/j.paid.2015.03.039.

Ministry of Environment, Science and Technology, 2009. National Indoor Air Quality Standards and Implementation Guideline. Government, of Nepal. https://nepalindata.com/resource/national-indoor-air-quality-stanards-and-implementation-guideline-2009/. (Accessed 29 August 2024).

Nila, S., Shrestha, C., Maharti, H.M., Horwell, C.J., Pelupessy, D.C., Kendal, R.L., Dhimal, M., Covey, J., Unpublished results. Children's Preferences for Features and Designs of KN-95-Style Respirators: a Comparative Study between Indonesia and Nepal. (Submitted to PLoS One).

Niu, X., Koehler, R.H., Yermakov, M., Grinshpun, S.A., 2023. Assessing the fit of N95 filtering facepiece respirators fitted with an ear loop strap system: a pilot study. Ann. Work expo. Health 67, 50–58. https://doi.org/10.1093/annweh/wxac051.

O'Kelly, E., Arora, A., Pirog, S., Pearson, C., Ward, J., Clarkson, P.J., 2022. Face mask fit hacks: improving the fit of KN95 masks and surgical masks with fit alteration

techniques. PLoS One 17, e0262830. https://doi.org/10.1371/journal.pone.0262830.
OSHA, 2019. Appendix A to § 1910.134 - fit testing procedures (mandatory). https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.134AppA. (Accessed 28 August 2024).
Preest, E., Greenhalgh, T., Farrier, C., van der Westhuizen, H.M., 2024. Children's experiences of mask-wearing: a systemic review and narrative synthesis. J. Eval. Clin. Pract. 30, 585–621. https://doi.org/10.1111/jep.13982.
van der Sande, M., Teunis, P., Sabel, R., 2008. Professional and home-made face masks reduce exposure to respiratory infections among the general population. PLoS One 3, e2618. https://doi.org/10.1371/journal.pone.0002618.
Smart, N.R., Horwell, C.J., Smart, T.S., Galea, K.S., 2020. Assessment of the wearability of facemasks against air pollution in primary school-aged children in London. Int. J. Environ. Res. Publ. Health 17, 3935. https://doi.org/10.3390/ijerph17113935.
Steinle, S., Sleeuwenhoek, A., Mueller, W., Horwell, C.J., Apsley, A., Davis, A., Cherrie, J. W., Galea, K.S., 2018. The effectiveness of respiratory protection worn by communities to protect from volcanic ash inhalation. Part II: total inward leakage tests. Int. J. Hyg Environ. Health 221, 977–984. https://doi.org/10.1016/j.ijheh.2018.03.011.
UNICEF, 2025. Children's Environmental Health Collaborative's Knowledge Library. https://ceh.unicef.org/events-and-resources/knowledge-library (accessed 20 March 2025).
WHO, 2018. Air pollution and children's health. Prescribing clean air. Summary. https://iris.who.int/bitstream/handle/10665/275545/WHO-CED-PHE-18.01-eng.pdf?sequence=2. (Accessed 29 August 2024).
WHO, 2021. WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. https://www.who.int/publications/i/item/9789240034228. (Accessed 29 August 2024).
Yu, Y., Jiang, L., Zhuang, Z., Liu, Y., Wang, X., Liu, J., Yang, M., Chen, W., 2014. Fitting characteristics of N95 filtering-facepiece respirators used widely in China. PLoS One 9, e85299. https://doi.org/10.1371/journal.pone.0085299.
Zhang, J., Mu, Q., 2018. Air pollution and defensive expenditures: evidence from particulate-filtering facemasks. J. Environ. Econ. Manag. 92, 517–536. https://doi.org/10.1016/j.jeem.2017.07.006.