# Do-It-Yourself (DIY) submicron- and micron- verification of 80% to 95% particle filtration efficiency (5x-20x protection factor) at nose level, facially unobstructed without masks using wearable devices, for clean air travel amidst air pollution (e.g. Delhi) and airborne infection (e.g. long flights) especially while eating/drinking

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**Background:** Infection prevention on passenger flights needs respiratory protection in a duration- and proximity- dependent manner, for which KN95 (~80% or ~5x protection factor) to well-fitted N95 (~95% or ~20x) masks are commonly used but incompatible with eating/drinking and prolonged use for many people. During the respiratory health crisis in New Delhi in mid-November 2025 reported as an abrupt rise in symptoms/hospitalizations, clean air without masks is needed, both at home and on the go (e.g. work, school, shopping, exercising, traveling). Particle concentration data immediately before and during November as well as longitudinal time-series data (five years) suggest a sustained protection factor of 10x (90%) to 5x (80%) may be sufficient to revert particulate exposure to pre-November levels.

**Materials and Methods:** A handheld 7-channel optical particle counter at 0.3 µm ("most penetrating particle size") to 10 µm was used in a Do-It-Yourself (DIY) manner to measure protection factor from smoke aerosols at 10 facial points at nose, eyes, mouth on mannequin head and an anemometer for airspeed at nose level. Three facially unobtrusive, maskless respirators (based on a US Patent # 12,343,573 B1) were prototyped and tested to for aerosol exposure in breathing/ocular zones without obstruction/occlusion of the horizontal and lower visual field to maintain forward and ground-visibility and enable eating/drinking. Each device was designed with off-the-shelf components to be mass-manufacturable: "Air" (442 g, 1 lb) used 1" pleated MERV 13 filter, "Pro" (907 g, 2 lb) additionally used a flat MERV 13 filter in series, and "Max" (1162 g, 2 lb 10 oz) used two 1" MERV 14 filters in series.

**Results:** At nose, mouth, and eye levels, maskless prototypes measured 87–98% aerosol filtration at 0.3 µm (2%–13% exposure), 94–99% at 1.0 µm, and 95–99% at 5.0 µm. At nose-level at 0.3 µm, "Air" measured 87% at 118 ft/min (1.3 mph), "Pro" measured 94% at 78 ft/min (0.9 mph), "Max" measured 98% at 177 ft/min airspeed (2 mph), a 10x improvement over prior wearable, unobstructed maskless devices reporting approximately 60% (< 70%) of 0.3 µm particles at nose level. Whereas in contrast to 0.3 µm, at 1.0 µm and 5.0 µm, "Air" measured 95% and 98% respectively. Number of tests, averages, and standard deviations and for each datapoint are provided herein.

**Conclusions:** The Do-It-Yourself (DIY) test method verifies indoor protection factor of 87%-97% for particulates at 0.3 µm at nose, mouth, and eye level of mannequin using mass-manufacturable, facially unobstructed wearable devices without burdens of masks, and 95% filtration for at 1.0 µm and 5.0 µm. Personally verified devices permitted access to mannequin mouth and all-day wearable protection from airborne infection and pollution indoors (or outdoors without significant wind), verifiable on mannequin using DIY test method. "Air" demonstrated ~5x or ~80% at 0.3 µm and ~20x or ~95% at 1.0 µm and 5.0 µm, while "Pro" and "Max" can reach higher protection, but not during windy conditions. An open

question remains by how much half-face shield permitting access to mouth can improve protection during windy conditions outdoors.

## Introduction: Is N95 necessary or overkill?

### *Delhi respiratory health crisis*

Abruptly in November, 2025, New Delhi has been described by some doctors as a “gas chamber” with patients streaming into hospitals with respiratory difficulties such as cough, asthma, and bronchitis [1] [2]. Although Delhi is the most polluted, a satellite-based assessment reported 60% of India’s 749 districts exceeded the National Ambient Air Quality Standard (NAAQS) of 40 µg/m³ with no district meeting World Health Organization (WHO) PM2.5 guideline of 5 µg/m³ [3]. Anecdotally, reports suggest this November in Delhi has been markedly worse than prior years [4], making an evening walk difficult [5] [6]. Patients are coughing due to pollution, and even if they have air purifier for relief at home, doctors recommend N95/FFP2 when out on the town (e.g. work, school, shopping, exercising, traveling) or if without sufficient air purification indoors [7]. A newspaper reports 80 per cent households in Delhi have had at least one member fall ill due to toxic air in the past month [8]. However, since people must go out for day to day activities and cannot wear masks for prolonged periods due to a variety of discomforts and limitations, even most AQI protestors at were seen unmasked and others taking a break from masking with their masks below their chin, 10:45 of [9].

Although N95 and KN95 are often used interchangeably, across a variety of manufacturers the average filtration efficiency of N95 respirators at 0.3 µm particle size was found to be much higher at 98% and more consistent than KN95 respirators at 81% [10] [11]. As seen on AQI.in™, changes in particulate concentrations that that triggered the Delhi crisis were between ~100 µg/m$^3$ in late October to ~300 µg/m$^3$ in mid-November [12]. As seen on Purple Air™, during Thanksgiving week in 2025, raw PM 2.5 in New Delhi within approximately 10x of San Francisco which is not reporting such a respiratory health crisis [13]. Daily PM 2.5 levels over five years across 39 stations spread across Delhi metro area in Figure 4 of [14] shows that if particle exposure is cut down in a sustained manner by a factor of:

- 4x-5x (75%-80%), then even on most of the worst days particulate dose will be around the year-round average level of 100 µg/m$^3$ from Figure 3 which can be seen in the chart is about four or five times lower than the peaks up at about 400-500 µg/m3.
- ~10x (90%), which is the blue line shown in Figure 4 then even on most of the worst days particulate dose will be around the more stringent national daily standard of 60 µg/m3,
- ~20x (95%) which is the yellow line shown in Figure 4 then even on most of the worst days particulate dose will be around the even more stringent WHO daily guideline of 15 µg/m3.

A study of particle size of pollution in Delhi reported most of the volume of particulate matter is between 0.1 to 1.0 micron ("Accumulation") and 2.5 microns to 10 microns ("Coarse") as shown in Figure 1 of [15], suggesting that protection factors would at least need to apply to these size fractions.

***Air Pollution***

The need for aerosol filtration to simultaneously address the dual concerns of toxic air pollution and airborne infection have been evident in California since at least 2020 when wildfires polluted the San Francisco Bay Area during the Covid pandemic [16]. In general, air pollution may arise from a variety of sources: accidents, wildfires, industrial sources, cooking, proximity to shooting guns (e.g. at a gun range), transportation (e.g. exhaust, brake dust). In 2025, the Los Angeles fires resulted in aerosol and vapor toxicity on a metropolitan scale, exposed the bottlenecks of masks necessitating indoor air cleaning for “collective protection.” These fires also triggered California’s statewide adoption of the 2023 CDC recommendation for 5 air changes per hour of aerosol filtration in all occupied spaces [17] which in principle provides a protection factor of approximately 10x from external pollution in a typical room assuming infiltration of 0.5 air changes per hour. Initially, on January 8, 2025, the California public health department (CDPH) posted on X for the public to use N95 masks to avoid inhalation of intense particulate pollution from the fires across the greater Los Angeles metropolitan area, as well to avoid respiratory viruses inside disaster shelters[18]. However, there was no public supply of N95 until a week later when city of Los Angeles announced N95s freely available at libraries on January 13 [19]. In the meantime, volunteers were handing out N95s and setting up air purifiers in disaster shelters (e.g. Pasadena Convention Center) yet many people could not wear these masks 24x7. By Jan 15, in reaction to the LA fires, CDPH upgraded its indoor air cleaning recommendation [20] to meet or exceed the 2023 CDC recommendation of 5 air changes per hour in all occupied spaces [21].

***Airborne viruses/bacteria***

Protection factors for infectious aerosols are modelled in the Supplementary Appendix. KN95 (5x) to well-fitted N95 (20x) masks are commonly used by passengers inflight but incompatible with eating/drinking and all-day/prolonged use for many people. For contagious viruses, susceptible exposure is duration dependent (number of hours) and for example a systematic review of aircraft-acquired SARS-CoV-2 transmission found passenger infection risk was flight duration-dependent, 25 times higher on long-haul flights versus shorter flights, and each hour increased the incidence rate by 1.53-fold [22]. Sports medicine physicians report athletes are more susceptible to air travel induced acute respiratory infections [23] [24]. If present, infector’s quanta emission rate (1 quanta is the minimum infectious dose inhaled) may range from 0 to over 1000 per hour based [25] [26] requiring commensurate protection factors

to prevent transmission, and ~10 hour exposure (e.g. berths on ships and submarines) approximately multiplies the protection factor needed to prevent contagion by an order of magnitude [27] [28] [29] [30]. At short distances in the "jet zone" from an infector [31] there is risk for pathogen transmission e.g., consider someone smoking a cigarette [32] [33]. In 1996 in Military Medicine, Col. Wiener called for lightweight respirators for bioaerosols wearable for prolonged periods [34] due to lack of early warning of biological attacks, airborne contagion, and difficulty of sustaining gas-mask use beyond 3-4 hours. A US Army study found that after 6-7 hours in hot climate using chemical protective clothing (including mask) soldiers experienced 17% to 23% increase in errors of omission and 40% lower productivity on routine tasks (e.g. map plotting) [35]. Wiener's paper specified protection of factors of 1000x (99.9%) for aerosol particles above 1 µm and 50x-100x (98 to 99%) for particles below 1 µm.

***Challenges of long-term use of masks and respirators***

Although many continue to use N95 masks regularly to avoid infections in public, the former CDC director Dr. Walensky commented, "when worn properly, N95 masks are suffocating, uncomfortable, and difficult to tolerate for long durations" [36]. Lightweight respirators include N95/N99/FFP3, but difficulties wearing them (non-compliance) were also anticipated by Wiener in 1996 and the problem has remained unsolved [37]. As recently as 2024, the JPEO-CBRND issued a request for information for "low-burden respiratory protection" for biological/pandemic threats [38]. During hearings about the COVID-19 pandemic, UK Health Security Agency testified FFP3 respirators were too uncomfortable for sustained long-term use by healthcare workers [39] [40] and one study pointed to staff-to-staff transmission in tea-rooms (unmasking to eat/drink) as a likely driver of viral transmission where masks are removed [41]. A draft CDC review concluded that difficulty breathing, headaches, dizziness, skin barrier damage, itching, fatigue, and difficulty talking were more frequently reported among N95 respirator users [42]. Respirators for infection prevention also cannot be worn by patients at the dentist due to the need for direct access to the patient's mouth.

Even if masks are perfectly functional, their protection fails when removed for eating, heat stress, or discomfort during extended airborne contamination. In order for individual protective equipment (IPE) to provide adequate protection from inhalation risks, such as gas masks and respirators (e.g. N95), they need to be tightly sealed to the face which typically causes:

1. Breathing resistance [43]
2. Heat discomfort [44] [45], and heat/humidity stress [C-1, C-6, and V-2 [46]] especially in warmer climates within 24-36 hours [5-3 [47]].
3. Prolonged IPE use results in "severely degraded" work rates [5.4 [48]] from fatigue, mistakes [V-2 [46]]
4. Difficulty communicating: harder to recognize people, obstruction of facial expressions, limited eye contact (for full face masks), hearing the user speak

[49]

5. Facial skin irritation, facial skin impressions
6. Prevents eating or drinking, hunger, and thirst, which will cause people to seek a clean environment or otherwise risk exposure when eating or hydrating.
7. A study suggests the N95 seal degrades rapidly if the wearer has a beard with hairs longer than a few millimeters [50].
8. Respirators (e.g. N95) may fog up eyeglasses if fitted with loose seals

There is a need for mask relief (e.g. selective unmasking) [A2.3.7 [48] and II-22 [46]] by more frequently [C-5 [47]] taking off masks or suits for a short breaks (work/rest cycles) [Tables C-2, C-6 of (51)] during extended mask use. Powered air purifying respirators (PAPR), especially those which are loose-fitting, are meant to overcome some of these challenges especially related to heat but often require a backpack and still facially obstructive, cumbersome, and/or noisy to use [51].

A common denominator among airborne environmental risks to people are aerosols at differing levels of concentration and effect, with nose, mouth, and eyes being the most vulnerable entry points. The risks in all of the above scenarios can in principle be mitigated if not entirely eliminated with masks and respirators sufficiently effective from aerosols s (e.g. N95, gas masks) or powered air purifying respirators (PAPRs), but they are unsustainable for long-term, daily use otherwise they could be worn continuously like clothes or eyeglasses.

***Do-It-Yourself (DIY) Testing of Maskless Respiratory Protection Devices at 0.3 µm, 1.0 µm, and 5.0 µm at nose level***

For aerosols, most difficulties with long-term use of respirators are caused by facial obstruction and/or face seals that also obstruct eating, drinking, and sleeping. The 0.3 µm particle size is known as approximately the "most penetrating particle size", whereby the aerosolized particle contamination filtration efficiency is typically lower than substantially larger particles [52] for which calibrated, handheld optical particle counters are readily available. Subsequently testing of N95 masks by NIOSH has been updated to use a size of about 0.075 µm [53], but regardless of which size is used if the mass fractions of particulates below 0.3 µm are expected to be minimal or their filtration efficiency is expected to be higher, testing at 0.3 µm in principle provides reasonable assurance of particle filtration.

For air pollution, filtering of submicron sized particles (< 1.0 µm) appears necessary if they comprise 70□%–80□% of the mass [54] [55] or more, and if so the 0.3 µm filtration efficiencies remain relevant for that application. For infectious bioaerosols, there remains considerable debate and uncertainty about the relative importance of submicron versus micron

particles. The reason is the percentage of infectious virus/bacteria in submicron versus micron particles (< 1.0 µm versus > 1.0 µm) depends on several competing and unknowable factors that depend on pathogen, host, and environment (exhalation from deep lung versus upper respiratory pathway, evaporation or condensation before inhalation, temperature, humidity). For example, in one study, more of the viable virus from human subjects was observed in submicron respiratory aerosols than micron and above [56], whereas in another study most of the genetic material was captured in micron and above [57].

In other publications wearable aerosol filtration devices either above or below the breathing zone, some have reported 95% or greater for particles sized around 0.3 µm directly at the output of the air filtration but have apparently not reported 95% for particles sized around 0.3 µm at nose level from submicron contaminants entering the breathing zone without occlusion/obstruction of the horizontal and lower visual field needed to maintain forward and ground-visibility [58] [59] [60] [61] [62] [63] [64].

A salinity gradient between 0.5 to over 30 parts per thousand in the estuary where a freshwater river meets a saltwater ocean has been documented [65]. By analogy, the “Airborne Estuary” is a 90-99% aerosol gradient at the boundaries where filtered (clean) air stream meets a source or infiltration of toxic surrounding chemical or biological aerosols. In this research we investigate feasibility of techniques resembling an “Airborne Estuary” to reach a desired target of 80%-95% aerosol exposure reduction with maskless respiratory protection devices.

In the next sections we describe and evaluate the protection factors from prototype unobtrusive maskless respirators. Air purifiers at home today are analogous to landline telephones of 30 years ago, and the promise of maskless respiratory protection is analogous to cell phones. They were designed, built, assembled, and tested entirely from off-the-shelf components, not dependent on custom manufacturing techniques (e.g. injection molding), and manufactured for large secondary markets with established demand from consumers and businesses for supply chain resilience in case of a demand-surge as seen for N95 during 2020 when they became unavailable.

## Methods

***Construction, Materials, Manufacturing, and Supply Chain***

We investigated, developed, and evaluated the protection factor of maskless prototypes: unobtrusive maskless respirators designated “Air,” “Pro,” and “Max” as mounted on a standard mannequin head shown in Figure 1 (A) to (C) based on a US Patent # 12,343,573 B1. They were assembled and tested using cap-mounted, lightweight fans drawing externally contaminated air through filters, balancing filtration efficiency with air resistance to modulate the aerosol field around breathing and ocular zones permitting eating/drinking without occlusion/obstruction of the horizontal and lower visual field needed to maintain forward and ground-visibility. The devices were cut, assembled, and tested using mass-manufactured materials (e.g. aluminum

sheet), PC case fans (12-volt DC), and HVAC filters from commercial-off-the-shelf (COTS) supply chain. Although prototypes were hand-assembled, they are not dependent on specialized manufacturing techniques (e.g. injection molding) and can transition to assembly-line production based on availability of COTS components.

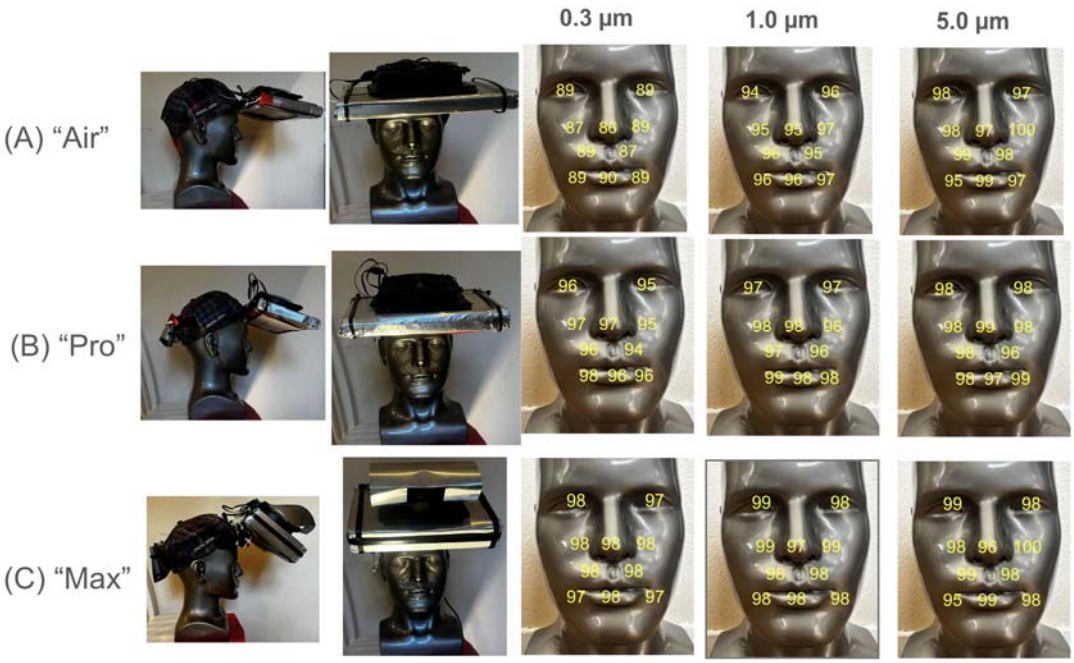


**Figure 1:** (A) "Air" using Arctic P12 and MERV 13 (6"x9") with its pleats are oriented perpendicular to direction facing user, tilted using friction hinges attached to brim of hat (B) "Pro" similar to "Air" except with more powerful Arctic P12 Max fan and a second flattened MERV 13 filter below first pleated MERV 13 filter and counterweight in back (C) "Max" is similar to "Pro" except it uses two pleated 6"x9" filters and brackets to raise the assembly closer to the head, adds rain guard above fan

For aerosol filtration, all devices relied on aerosol filters cut from approximately 0.75" thick pleated HVAC filters rated MERV 13 or MERV 14, either one or two in series made by 3M™ (Filtrete™) cut to 6"x9". The additional flat filter in "Pro" was flattened from a pleated MERV 13 filter made by Lennox™. The direction of pleats was perpendicular to the direction facing the wearer of the device. Although HEPA filters could be used, they would have required two or more of the most powerful case fans available stacked in series to generate the static pressure needed to overcome the higher level of air resistance, making them heavier, larger, and less wearable. Use of filters cut from N95 masks did not result in a wearable maskless device because of their air resistance [66]. This reflects the competing physical challenges for a wearable, maskless (unsealed) device to achieve stringent targets of 95% filtration at 0.3 µm at nose level:

- Filtration-wearability vicious cycle: each extra particulate contamination filter that is added in an airstream (in series) to increase filtration efficiency also introduces air resistance, which in turn decreases airflow velocity, and therefore must be then counteracted by increasing fan airflow and air pressure, which in turn increases noise generated, size, weight, and power consumed making the device unwearable (the 'filtration-wearability challenge').
- Intermixing of submicron particles: When the face is unobstructed, there is a relatively large distance (approximately 2-3 inches or more) between the filter (positioned above or below the breathing zone) and the nose that allows for intermixing of the filtered air with surrounding contaminated air as it travels, by the time it reaches the nose level. This intermixing occurs near the boundaries of the filtered airflow in any unsealed gaps possibly through a variety of aerodynamic and fluidic processes such as entrainment, turbulence, diffusion, pressure differential, shearing, etc. potentially in a particle-size dependent manner. The intermixing effects particles having a size of about 0.3 µm since a moving airstream also allows particles to enter (mix) from adjacent, stationary contaminated air in unsealed systems with large gaps.

A transparent (half) face shield that extends from the eyes down to the mouth level can further prevent external aerosol mixing permitting eating and drinking. With the half face-shield, future prototypes could substantially reduce the size and hence weight of the filters.

The fans used in the maskless devices were either P12 or P12 Max made by Arctic and powered by 12V DC portable batteries.

***Instruments***

Instruments used to take measurements in the experiments are listed below:

- OPC1: Particle counts were measured with ambient aerosols or generated smoke aerosols using a handheld optical particle counter calibrated by the manufacturer (Temtop™ PMD 331™) which reports particle counts per liter across 7 channels: 0.3 µm, 0.5 µm, 0.7 µm, 1.0 µm, 2.5 µm, 5 µm, and 10 µm [67]. A hose was used to precisely direct the particles from each location on the face to the input of the particle counter.
- OPC2: In some instances, as secondary confirmation, particle counts at 0.3-0.5 µm were verified using a second optical particle counter (TSI™ Omnitrak™ PM module) which reports particle counts per liter across five channels: 0.3-0.5 µm. 0.5-1.0 µm, 1.0-2.5 µm, 2.5-4.0 µm, 4.0-10 µm. Since the input to this particle counter is large (2"x1"), use of a hose was not feasible.
- FTM: Airspeed was recorded using a vane anemometer (BTMETER™ BT-100™ Handheld Anemometer).
- DBA: Noise was measured using the NIOSH Sound Level Meter app on an iPhone 14.
- OZ: Weight was measured using a standard desktop weight scale (Escali™).

- WATT: Power consumed by each device was measured using a Kill-A-Watt™.

All tests were conducted indoors at room temperature of approximately 74 degrees Fahrenheit.

***DIY Test Procedure***

Filtration efficiency for aerosol concentrations was computed using the formula, 1 - location concentration / intake concentration:

- OPC1 was used to compute the filtration efficiency at 0.3 µm at each of the 10 locations on the face of the mannequin by recording for 10 seconds sequentially. Intake particle concentration (particles per liter) above the device (near the fan intake) were recorded also for 10 seconds, before and after recording at each of the 10 locations and then averaged.
- For secondary confirmation, OPC2 was used to compute the filtration efficiency at 0.3-0.5 µm, for 5 minutes at nose level while the fan was on, and before and after when fan was off also for a duration of 5 minutes each and averaged.

Filtration efficiencies with OPC1 were measured five times and averaged, except for “Max” they were measured 10 times and then averaged. Airspeed at chin level and noise within 3 inches of the ear were measured five times and averaged. Figure 2 shows an example the “Air” device with input of the hose connected to OPC1 positioned between the right nostril and mouth of mannequin head.

**Figure 2:** OPC1 with intake input of hose positioned between the right nostril and mouth of mannequin head.

## Safety Notes

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## Results

### *Test Results*

Details of the devices and measurements (and their standard deviations in case of multiple measurements) are in Table 1. Filtration efficiency for particles sized 0.3 µm, 1.0 µm, and 5.0

µm at 10 different locations across the face (nose, mouth, eyes) are shown for “Air,” “Pro,” and “Max” are also shown in Figure 1. A 20-second YouTube short [68] demonstrates a nebulizer to visualize the flow of water-based aerosols (representing external aerosolized contamination) at different points of the breathing zone when “Max” is turned on and off. First the nebulizer is positioned to introduce aerosols from below the nose, then it is introduced from in front of the nose. In both cases the aerosol can be seen to be deflected from the nose, mouth and eyes when the device is turned on.

| | (“Air”) Single MERV 13, 6” x 9” | (“Pro”) Dual MERV 13 pleated/flat, 6” x 9” | (“Max”) Dual MERV 14, 6” x 9” |
|---|---|---|---|
| Number of tests | 5 | 5 | 10 |
| Below left nostril (0.3 µm, 1.0 µm, 5.0 µm) | 87%, 95%, 98% | 94%, 96%, 96% | 98%, 99%, 98% |
| STDEV Below left nostril | 3%, 2%, 3% | 3%, 2%, 2% | 1%, 1%, 3% |
| Below right nostril (0.3 µm, 1.0 µm, 5.0 µm) | 89%, 96%, 99% | 96%, 97%, 98% | 98%, 98%, 99% |
| STDEV Below right nostril | 2%, 1%, 1% | 2%, 2%, 3% | 1%, 1%, 2% |
| Side of left nostril (0.3 µm, 1.0 µm, 5.0 µm) | 89%, 97%, 100% | 95%, 96%, 98% | 98%, 99%, 100% |
| STDEV Side of left nostril | 2%, 2%, 0% | 3%, 2%, 2% | 0.4%, 1%, 2% |
| Side of right nostril (0.3 µm, 1.0 µm, 5.0 µm) | 87%, 95%, 98% | 97%, 98%, 98% | 98%, 99%, 98% |
| STDEV Side of right nostril | 3%, 2%, 3% | 1%, 1%, 2% | 1%, 1%, 5% |
| Front of nose (center) (0.3 µm, 1.0 µm, 5.0 µm) | 86%, 95%, 97% | 97%, 98%, 99% | 98%, 97%, 96% |
| STDEV Front of nose (center) | 2%, 2%, 3% | 1%, 2%, 2% | 1%, 2%, 5% |
| Front of mouth (center) (0.3 µm, 1.0 µm, 5.0 µm) | 90%, 96%, 99% | 96%, 98%, 97% | 98%, 98%, 99% |
| STDEV Front of mouth (center) | 1%, 1%, 3% | 2%, 1%, 1% | 1%, 1%, 2% |
| Left of mouth (0.3 µm, 1.0 µm, 5.0 µm) | 89%, 95%, 99% | 96%, 98%, 99% | 97%, 98%, 98% |
| STDEV Left of mouth | 2%, 3%, 3% | 3%, 2%, 1% | 1%, 1%, 4% |
| Right of mouth (0.3 µm, 1.0 µm, 5.0 µm) | 89%, 96%, 95% | 98%, 99%. 98% | 97%, 98%, 95% |
| STDEV Right of mouth | 2%, 2%, 5% | 1%, 1%, 2% | 1%, 1%, 6% |
| Left eye (0.3 µm, 1.0 µm, 5.0 µm) | 89%, 96%, 97% | 95%, 97%, 98% | 97%, 98%, 98% |
| STDEV Left eye | 3%, 1%, 3% | 3%, 3%, 3% | 1%, 1%, 3% |
| Right eye (0.3 µm, 1.0 µm, 5.0 µm) | 89%, 94%, 98% | 96%, 97%, 98% | 98%, 99%, 99% |
| STDEV Right eye | 2%, 2%, 3% | 3%, 3%, 2% | 1%, 1%, 2% |
| Omnitrak PM (0.3-0.5 µm) | 90% | 98% | 97% |
| Airspeed (feet per minute) | 118 | 78 | 181 |
| STDEV Airspeed | 0 | 0 | 8 |
| Noise (dBA) | 50 | 62 | 62 |
| STDEV Noise | 1.5 | 0.7 | 0.7 |
| Weight (oz) | 15.6 | 32.0 | 41.8 |

**Table 1:** Measurements of maskless respirators.

## Experimental Limitations

Although this study included tests of aerosol filtration efficiency at 10 locations on the face of a mannequin, it did not attempt to measure the (in)sensitivity to varying head sizes, facial shapes, heavy breathing, eating, or drinking. This study also does not measure the effect of movement (e.g. walking, running), ambient wind currents, and strong air jets generated by exhalations from nose or mouth of another person facing the wearer's face. Although the higher the air speed that the maskless device generates at nose level the less affected it is likely to be.

One question is by how much the vertical airflow in maskless devices provide protection to or from others who may be directly in front of the wearer during close-contact (e.g. < 3 feet) if the wearer's breathing and exhaled particles are channeled downward instead of directly into the person they are speaking with. This is like how ceiling fans displace accumulations of infectious particles during close-contact. For example, a mannequin placed directly underneath a ceiling fan was exposed to approximately 95% fewer aerosol particles from a simulated cough 5 feet away when the fan was on compared to when it was off [69]. Another question is whether a 'network effect' occurs in a room if more people in the room use a maskless protection device, since a greater volume of air within the room will also get filtered.

If a sufficiently airtight seal to the face can be formed using a traditional gas mask or N95, those may be more robust to windy conditions. However, such face seals often have leaks which are overcome by maskless devices especially for indoor environments (when wind speed is limited). If a half face shield is included with the maskless device, one question is whether resilience to wind or exhalations from another person facing the wearer's face can increases further. Theoretically, results from the ambient test aerosols used in this study in some instances might not extrapolate directly to removal of aerosols with specific viruses/bacteria (e.g. SARS-Cov-2), different kinds of pollution, and particle sizes other than those at reported herein for 0.3 µm, 1.0 µm, and 5.0 µm (such as 0.075 µm).

## Conclusions

Prototype maskless respirators measured 87–98% aerosol filtration at 0.3 µm at nose level (2–10% exposure), which appears to be a 10x improvement over published wearable devices that do not occlude/obstruct the horizontal and/or lower visual field needed to maintain forward and ground-visibility and enable eating/drinking:

- Max with larger 6” x 9” MERV 14 pleated filters (two in series) was able to exceed 97% across all 10 locations and 98% in some locations representing the best, most uniform result for aerosol filtration efficiency across all the six devices tested.
- Pro, considerably lighter than Max, demonstrated 94%-97% across all 10 locations
- Air used measured 50 dBA near the ear with some ambient noise resulting in filtration efficiencies more than 85% uniformly across all 10 locations. In contrast to 0.3 µm, Air measured 95% and 98% at 1.0 µm and 5.0 µm, respectively.

The DIY test method demonstrates a personally verifiable indoor protection factor of 5x-20x, 87%-98% for particulates at 0.3 µm at nose level of a mannequin using mass-manufacturable, facially unobstructed wearable devices without burdens of masks. Using the calibrated handheld particle counter, the protection provided to each mannequin (wearer) of the maskless device may be verified using the test protocol demonstrated on the mannequin in this study, like an optometrist verifies fit and function of eyeglasses in an eye shop, and adjustments made as necessary to ensure filtration efficiency, airspeed, and forward visibility of maskless devices.

- “Air” (> 5x or > 80% at 0.3 µm) might be sufficient reduce particulate exposure to pre-November levels, that of previous years, or other Indian cities not reporting a similar crisis.
- These devices as tested were designed to permit access to the mannequin mouth for eating/drinking and all-day wearable protection from airborne infection and pollution indoors or outdoors but only without significant wind. As shown in Figure 3, although as-yet untested, the addition of an optional half- or full- face shield still permitting access to the mannequin mouth for eating/drinking is expected to improve protection during windy conditions outdoors by shielding from wind and guiding the filtered airflow towards the face.
- As debates continue about photochemistry induced pollution from UV for pathogen inactivation [70] and ionizers/electrostatic precipitation [71], the maskless devices described (based on fans and filtration) do not rely on those techniques.

In the US, the N95 mask incorporates manufacturing quality control administered by NIOSH, including spot checks of batches but not checks at the level of each individual mask. To transparently verify quality control for each individual device at time of assembly, a unique serial number can be assigned to each maskless device and video recording of the test procedure performed on that device with a mannequin head can be retained for archived review independently of the manufacturer.

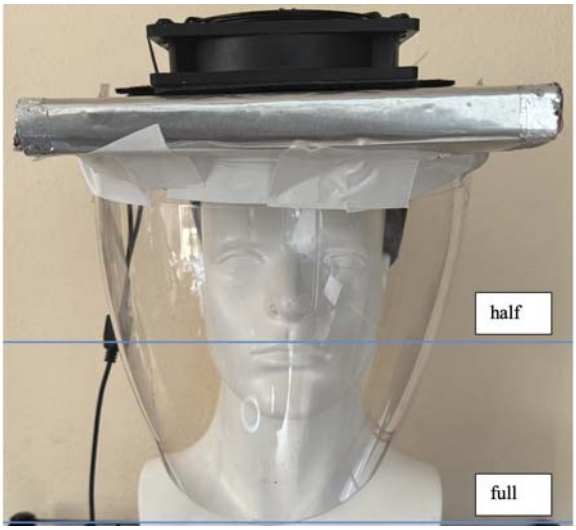


**Figure 3:** Adding a face shield, full (shown) or half to allow eating/drinking is expected to improve protection during outdoor windy conditions but as-yet untested

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***Supplementary Appendix: Individual Risk Model For Contagious Bioaerosols and Protection Factor***

This section is not intended as clinical or public health recommendations, but as illustrative Wells-Reilly modeling. Individual infection risk (P) to susceptibles in a room or shelter with infectors is modeled according to the Wells-Reilly equation as [72]:

$$P = 1 - e^{-Q(T)}$$

where Q(T) is the average number of infectious quanta inhaled by a susceptible individual during that time T. This formula may be interpreted as applying the Poisson distribution to the inhalation (arrival) of a random number of infectious quanta with average Q(T) into the respiratory system of the individual who is at risk. Q(T) can further broken down into the product:

$$Q(T) = T\,B\frac{C}{D}$$

where B is the breathing rate of the individual at risk, C is the concentration of pathogen per unit volume in the room, and D is number of pathogens in one infectious quanta.

Under the well-mixed assumption, in steady state C can be deduced using the mass-balance relationship where the rate of exhalations of pathogen by infector(s) in the room (E) is exactly counterbalanced by the rate of removal of virus achieved by filtration or ventilation system in the room [equation 2 [73] and equation 3 of  at equilibrium [25]]. The concentration of virus per unit volume (C) lowered by ventilation to satisfy the mass-balance condition to be function of (E) the total quanta emission rate of all infectors present and the rate of clean or filtered air flow introduced into the room (R) under the well-mixed assumption is:

$$E = R\,\frac{C}{D}\ or\ \frac{C}{D} = \frac{E}{R}$$

$$so\ Q(T) = T\,B\,\frac{E}{R}$$

P can therefore be estimated from Q(T) as a function of E, T, and R – the quanta emission rate, duration of exposure, and ventilation/filtration rate which are independent of the number of susceptible people regardless of the size/area/volume of the room under the well-mixed assumption. The to the extent the well-mixed assumption is a valid approximation, same estimate applies for a shelter, a ship, or an airplane regardless of its size. A mask reduces the exposure by the its protection factor (F) e.g. 20x for N95, 100x for N99, etc. The effect of mask can be

modeled as reducing Q(T) by a factor of F in the denominator, equivalent to scaling the ventilation rate:

Figure S1 and Figure S2 show F as a function of E (quanta emission rate), R (ventilation/filtration rate) for T = 1 hour (e.g. classroom or lunch with infector) and T = 8 hours (e.g. sleeping in same room as infectors). R ranges from 1 to 10,000 CFM (assuming breathing rate B = 0.52 cubic meters per hour. Quanta emission rate ranges from 0 to 1000 representative of values found in [25] and [26]. Both Figure S1 and Figure S2 illustrate the rise in infection risk from 0-100% as a function of infector's quanta emission rate and countervailing drop in risk as clean air airflow rate rises. The rapid increase of infection risk when people are together for prolonged periods such a 8 hours (Figure S2), as opposed to just one hour (Figure S1), can be seen clearly from the dependence of individual risk on total airflow rate where even a thousand CFM maybe sufficient to keep the infection risk low for 1 hour, much more exceeding 5,000 CFM maybe needed for 8 hours depending on the projected quanta emission rate under the well-mixed assumption.

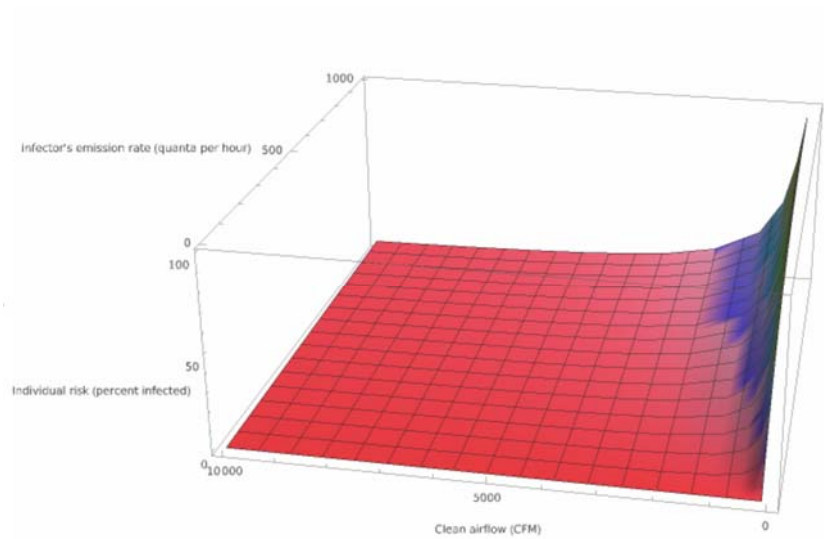


**Figure S1: Individual infection risk over 1 hour versus infector quanta emission rate (per hour) and filtration/ventilation airflow rate (cubic feet per minute)**

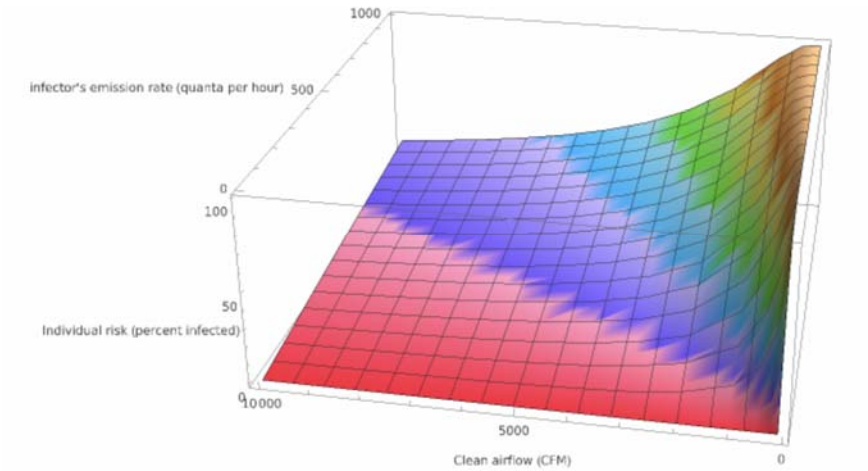


**Figure S2: Individual infection risk over 8 hours versus infector quanta emission rate (per hour) and filtration/ventilation airflow rate (cubic feet per minute)**

The effect of adding mask either to the susceptible(s) or to the infector(s) may therefore be visualized on Figure S1 and Figure S1 by simply "boosting" the ventilation (R) by the mask's protection factor F. By combining the ventilation (R) with a mask protection factor F=20 (95%), the 8-hour risk rapidly drops as shown in Figure S3, to levels below the 1-hour exposure of Figure S1 since time (T) is in the numerator of the expression for Q(T).

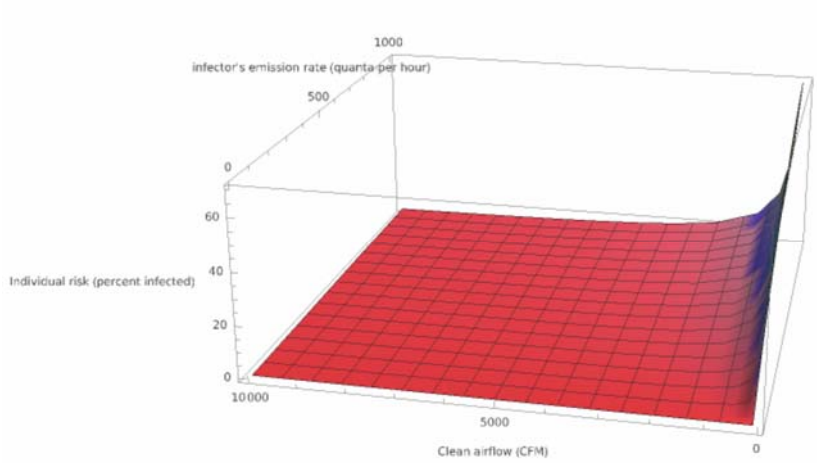


**Figure S3: Individual infection risk over 8 hours versus infector quanta emission rate (per hour) and filtration/ventilation airflow rate (cubic feet per minute) with added protection factor F=20 (95%)**

The well-mixed assumption may not always apply even with good ventilation when people work or sit with others in close proximity (e.g., while eating lunch less than 3 feet from each other for 30 minutes) especially in the "jet zone" from an infector [31] or who have fleeting contact in hallways are at risk for pathogen transmission [74]. At such short distances, the infector's emissions do not have enough time to dilute inside the room before reaching a susceptible person

nearby, particularly during prolonged exposure (e.g., consider someone smoking a cigarette). Empirical evidence supports this distance-dependent risk: a study of COVID-19 transmission in prisons found that inmates were much more likely to be infected if they were exposed to another infected person within their own cell than within the same cell block, possibly because exposure within the same cell is much closer and for a longer duration [32]. Also a study of digital contact tracing of SARS-CoV-2 among 7 million close contacts (e.g., within about 6 feet) similarly concluded that although many exposures were short in duration, recorded transmissions typically resulted from exposures lasting from an hour to multiple days [33]. In summary, infection risk is both bioaerosol concentration-dependent and exposure duration-dependent, which to reduce transmission risk in scenarios with infection risk, and needs a high degree of continuous collective and personal protection suitable for extended-use [30].