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# Improvement in Fitted Filtration Efficiency of N95 Respirators With Escalating Instruction of the Wearer

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**Introduction:** Fitted filtration performance of an N95 respirator may benefit from differing levels of instructions.

**Methods:** Using a modified Occupational Safety and Health Administration fit test protocol, we measured fitted filtration efficiency for an N95 respirator in 21 screened, healthy participants given 4 levels of escalating instruction: (1) uninstructed (baseline), (2) written/pictorial manufacturer instructions, (3) step-by-step video demonstration, and (4) staff instruction (visual inspection of respirator fit and verbal suggestions to adjust when applicable).

**Results:** Baseline fitted filtration efficiency was not significantly different between participants with or without previous experience of N95 use. Clear improvements in fitted filtration efficiency were observed progressing from baseline (average=86.1%) to manufacturer paper instructions (93.3%), video instructions (97.5%), and post staff intervention (98.3%). Baseline fitted filtration efficiency values were significantly lower than those after video instruction ($p<0.037$) and staff intervention ($p<0.033$) sessions.

**Conclusions:** Beyond uninstructed wear or provision of manufacturer instructions, efforts to train and instruct users in proper respirator fit principles with visual feedback are likely to yield benefits to public health outcomes in reducing respiratory exposure during air quality emergencies such as airborne viral outbreaks and wildland fires.
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## INTRODUCTION

Disposable N95 respirators represent a primary intervention to protect against inhalational exposures, including the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus, wild-land fire smoke, and other air quality emergencies. Therefore, realizing the rated performance of N95 respirators has important public health implications. Before more recent use cases during emergency environmental conditions, respiratory protection was more commonly implemented as a safety requirement to protect workers from hazardous exposures in occupational settings. To ensure the reliability of such

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**Table 1.** Participant Characteristics

| Characteristic | All participants (N=21) |
|---|---|
| Age (years), mean (SD) | 26.0 (4.7) |
| Sex, *n* (%) | |
| Male | 7 (33%) |
| Female | 14 (67%) |
| Race/ethnicity, *n* (%) | |
| Asian | 2 (9.5%) |
| Caucasian | 19 (90.5%) |
| Education level, *n* (%) | |
| High school or trade school | 2 (9.5%) |
| College or higher | 19 (90.5%) |
| BMI (kg/m$^2$), mean (SD) | 23.6 (2.4) |
| Previous N95 usage, *n* (%) | |
| Yes | 11 (52%) |
| No | 10 (48%) |

protection, workplace regulations in the U.S. (and other countries) require employee training and fit testing with a minimum pass level before their usage.[1] However, studies have raised doubts over whether an untrained person can properly put on (don) an N95 respirator. Results on this topic are equivocal, with some reporting low percentages of users that show proper technique[2,3] and others suggesting a potential to achieve a better fit with the aid of a video or other assistance.[4,5] To determine the amount of instruction necessary to achieve optimal protection, in this study, we measured the fitted filtration efficiency (FFE) of an N95 respirator worn by participants at baseline and after receiving escalating levels of instruction.

## METHODS

The study was approved by the University of North Carolina at Chapel Hill IRB and the U.S. Environmental Protection Agency human subjects review office. Participants (N=21, 67% female, aged=26.0 ± 4.7 years) (see Table 1 for additional characteristics) were recruited to participate in this study. Although targeted enrollment was 20 participants, with assessment after every 10, on the basis of recruiting efforts and timing parameters, the final count included 1 additional participant (see CONSORT flow chart, supplemental materials). Eligible participants also needed to meet additional criteria including age range of 18−35 years; BMI between 19 and 32; normal lung function and electrocardiogram; no history of cardiovascular disease, chronic respiratory disease, cancer, uncontrolled hypertension (≥140 systolic, ≥90 diastolic), or diabetes; fully vaccinated against coronavirus disease 2019 (COVID-19); and willingness to shave facial hair for male participants. To avoid advance subject preparation, some details of the study were withheld until the study day.

During the single in-person testing session, subjects answered a questionnaire on previous experience with masks, specifically focused on the number of times they had worn an N95 respirator, that is, previous experience = times used ≥1, and whether they had received any training. Participants underwent a modified version of the Occupational Safety and Health Administration Quantitative Fit Testing Protocol (Modified Ambient Aerosol CNC Quantitative Fit Testing Protocol for Filtering Facepiece Table A−2—RESPIRATORS, available online) in a custom-built exposure chamber supplemented with aerosolized sodium chloride particles (TSI model 8026).[6−9] The size of the sodium chloride particles was characterized using a Scanning Mobility Particle Sizer (TSI model 3938), and the median diameter was approximately 50 nm. Two separate condensation particle counters (TSI model 3775) recorded ambient and behind-mask particle concentrations. Each test lasted for approximately 3 minutes, and all used a trifold 3M Aura 9205+, with a metal test port inserted. Although the study's intent was to use a different model respirator (3M 8210), there were several reasons for switching to the Aura 9205+ model. Logistically, our supply of the 8210 model was severely limited, and given the uncertainty around obtaining additional supply during the COVID-19 pandemic, we opted to proceed with the 9205+ to prevent any delays in study completion. Furthermore, there were benefits that included having individually sealed packages, a possibly higher degree of comfort, and a flat-fold design that is more easily distributable to the public, for example, through postal delivery. Of note, the written/pictorial model–specific manufacturer instructions were available on laminated paper for reference during manufacturer instruction and subsequent conditions. The pictures used were the same as those shown on the individual wrapper packaging, which was discreetly removed from view before baseline testing. The beginning of the video demonstration featured narration reminding the user to refer to manufacturer instructions when putting on an N95, further specifying that the video would feature general instructions as shown using a commonly available model (see supplemental materials). Testing sessions for all participants proceeded in an escalating manner as follows: for baseline testing, participants donned the respirator uninstructed and were retested after reading manufacturer instructions[10] and again after viewing a short (3-minute) video demonstrating step-by-step donning of a 3M 8210 N95 (the script and video were developed by Environmental Protection Agency personnel and featured a Public Health Officer donning the respirator with audio narration and on-screen text and graphics to reinforce key points; pause and rewind use was encouraged for any additional review desired). Just before the final test, research staff conducted a visual inspection of the donned respirator and verbally intervened as needed to obtain the best fit possible.

FFE, calculated as (100 × [1–mask/ambient]) was the primary outcome variable for each participant and each test. A linear mixed-effects model with subject as the random effect was employed for the statistical analysis with Greenhouse–Geisser correction for unequal variances. Dunnett's multiple comparisons were conducted to compare FFE across the levels of instruction, and a linear regression analysis was carried out to examine whether previous N95 experience affected baseline FFE performance. GraphPad Prism 9 was used, with statistical significance set at $p<0.05$.

## RESULTS

Information about participants is provided in Table 1. Figure 1 shows scatterplots of FFE values with mean and

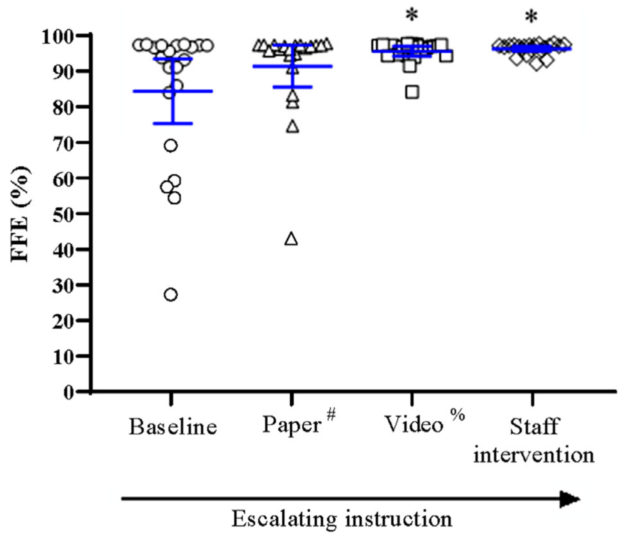


**Figure 1.** FFE (calculated as (100 × [1–mask/ambient] particle counts) percentages are shown for each participant across escalating instruction conditions (baseline, paper [manufacturer] instruction, video instruction, and staff-recommended intervention). The mean and 95% CI calculated for each condition are shown with blue lines. *=significant difference ($p<0.05$) from baseline in a linear mixed effect model with subject as a random factor. Paper (#) shows the laminated copy of text and pictorial instructional content from 3M 9200 Series package insert. Video (%) features a U.S. Public Health Officer demonstrating the process of putting on an N95 with audio narration and on-screen text and graphics to reinforce key concepts are shown. Participants could pause and rewind the video as desired to review specific steps or instructions. Each data point summarizes the average performance of a participant who performed the modified OSHA fit test exercises. Anonymized individual participant results are provided as supplementary material.
FFE, fitted filtration efficiency.

95% CIs. Previous N95 experience (yes=11; no=10) was a nonsignificant factor for baseline FFE values ($p=0.95$). Among the 11 participants who had worn N95 respirators before, only 1 reported being formally trained and achieved 98.7% FFE without any instructions at the baseline test. Overall, participants' FFE improved, progressing from baseline (average=86.1%) to manufacturer's instructions (93.3%), video instructions (97.5%), and post staff intervention (98.3%). A comparison between the top and bottom 5 performers at baseline indicated that escalating instructions reduced variability of FFE across the testing exercises for those who started with poor performance (Figure 2). By contrast, the top 5 baseline performers displayed largely consistent performance across escalating instruction. In both groups, 3 participants reported previous use, whereas 2 participants reported no previous use (total: 6 yes responses, 4 no responses), and the participant who reported previous training was not part of the top (or bottom) performing group. Considering all participants, average baseline FFE values were significantly lower than those of subsequent video instruction ($p<0.037$) and staff adjustment ($p<0.033$) test sessions. The most common mistakes made during testing involved improper usage or positioning of the straps and absent or improper adjustment of the metal nosepiece (Table 2). The number of mistakes was negatively correlated with FFE at baseline ($R=-0.65$), and donning errors noted by research staff decreased after increasing instruction. Results were similar excluding the participant who reported previous training with N95 respirators (baseline FFE=98.7%).

## DISCUSSION

Baseline FFE testing did not show any statistically significant difference between participants with and without previous N95 experience in our cohort of 21 participants. We report statistically significant improvement in FFE after video instruction and staff intervention compared with baseline testing. Given the exploratory (or hypothesis-generating) study design focused on improving the quality of respirator filtration participants could achieve, a larger randomized trial of untrained participants would bolster conclusions about the efficacy of escalating audiovisual instruction. This study design did not control for the potential effect of repeated practice, and a randomized trial of a subset of specific independent test conditions may be warranted. However, a recent study found that repeated donning of the same respirator was associated with variable fit factors achieved across 6 fit tests with the likelihood of a failed test increasing until the fourth test and then stabilizing.[11] One conclusion the authors of that report made is that users who reuse a respirator should be made aware of the need to strictly and consistently adhere to good donning practices. Although in our experiment, each participant used a single N95 respirator for the 4 repeated test sessions, repeated wearing (i.e., <30 minutes for all the tests) has been shown to have little impact on overall fit performance in previous studies.[11–13] Additional limitations of the study include the small sample size, which may bias the participant demographic and physical characteristics. This sample was younger, with a higher percentage of college-educated and female participants than the general population, which may have skewed baseline performance to better-than-expected levels, considering previous literature on uninstructed respirator wear.[2,3] Nonetheless, these findings suggest that members of the public can achieve highly protective levels of N95 respirator performance using video tutorial training. Such training may bolster the effectiveness of layered intervention strategies if they coincide with related protective

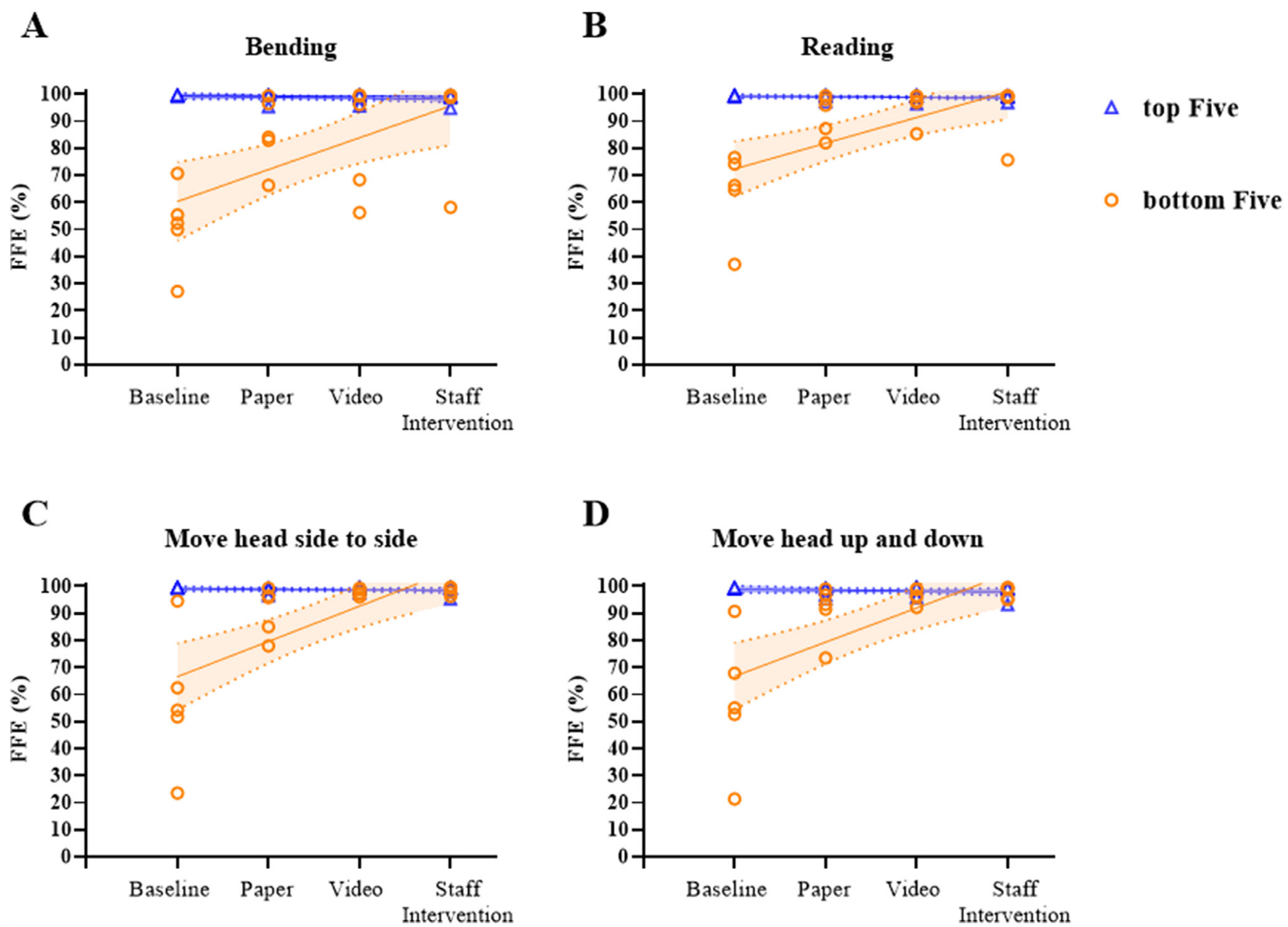


**Figure 2.** Exercise-specific FFE percentages shown separately for the top (blue) and bottom (orange) 5 performers from the baseline test. FFE is plotted for these groups per exercise starting from (along x-axis) baseline and progressing across the escalating levels of instruction. Panels correspond to (A) bending at the waist, (B) reading the rainbow passage, (C) moving head side to side, and (D) moving head up and down. Exercises B, C, and D were 30 seconds in duration, whereas A was 50 seconds for a total of about 3 minutes per complete OSHA test per instruction condition.
FFE, fitted filtration efficiency.

**Table 2.** Number of Participants (of 21) Who Made Mistakes When Donning the N95 Respirator

| Tests | Respirator panels | Respirator straps | Metal nosepiece | Other issues |
|---|---|---|---|---|
| Baseline | 1 | 16 | 10 | 3 |
| Paper | 1 | 9 | 2 | 0 |
| Video | 0 | 4 | 0 | 0 |
| Staff intervention | 0 | 0 | 0 | 0 |

*Note:* Participants were observed when donning the N95 respirator with escalating instructions, and any notable mistakes were recorded. Panel mistakes indicate absent or incomplete opening when donning. Strap mistakes include not separating the 2 straps, crossin g straps, bottom strap positioned over long hair, and top strap too low. Nosepiece mistakes include not molding the nosepiece at all or molding with one hand. Other issues include twisted straps.

measures (e.g., the 15 minutes of post–COVID-19 vaccination monitoring or time spent at clean-air shelters during wildfire smoke). Owing to more frequent N95 respirator usage outside of a workplace context, broad distribution of instructional videos (e.g., printed QR codes and public-service announcements on television and social media) could help to ensure viewing and awareness, increasing the likelihood of implementation of learned information.

## CONCLUSIONS

Given the increased availability and promotion of N95 respirators for use among the public, there is an urgency to determine what type of instruction is needed for the public to properly don N95 respirators and maximize their protection.[14] Studies have shown that respirators and respirator-type masks provide improved fitted filtration relative to cloth or procedure masks.[7–9] However, because N95 respirator use is traditionally associated with workplace scenarios that require fit testing and training, FFE performance in the public is likely to show more variability. The public may not read, comprehend, or execute written and pictorial instructions as provided by respirator manufacturers. Therefore, the likelihood of errors in donning, even among people with past usage, augments the need to provide training in real-world scenarios. Short videos that reinforce the basic principles needed to achieve optimal fit and protection may be a relatively low-cost technique to improve public health outcomes after the distribution of high-performance N95 respirators. Beyond reinforcement of these principles, after donning, users can inspect their fit in a mirror or ask another person to check for errors in the general fit and conformity of the material and seal with facial landmarks (nose and chin). These simple interventions have the potential to provide better and more consistent protection across the broadest segments of the population.

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The manuscript has been subjected to review by the U.S. Environmental Protection Agency, Center for Public Health and Environmental Assessment, and approved for publication.

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## CREDIT AUTHOR STATEMENT

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## SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.focus.2022.100014.

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