American Journal of Infection Control 44 (2016) 194-8

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Major article

Physiologic and fit factor profiles of N95 and P100 filtering facepiece respirators for use in hot, humid environments

Jung-Hyun Kim PhD, Tianzhou Wu MS, Jeffrey B. Powell MS, Raymond J. Roberge MD, MPH *

National Personal Protective Technology Laboratory, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Pittsburgh, PA

Key Words:
Filtering facepiece respirators
P100
N95
Hot humid environment
Fit factors
Thermophysiologic and subjective responses

Background: To determine if hot, humid ambient conditions impact filtering facepiece respirators' (FFRs') fit, and to evaluate differences in physiologic and subjective responses between N95 FFRs and P100 FFRs.

Methods: Twelve subjects had physiologic monitoring and subjective perceptions monitored over 1 hour of treadmill exercise (5.6 km/h) in an environmental chamber (35°C, relative humidity 50%) wearing an N95 FFR, P100 FFR, or no respirator. Respirator quantitative fit testing was done before and after exercise.

Results: There was no significant difference in pass rates for both FFRs on initial fit testing, but subjects who passed were more likely to fail the postexercise test with N95 FFRs ($P = .01$). Wearing FFRs increased the temperature of facial skin covered by the FFR ($P = .009$) and breathing discomfort ($P = .002$). No significant differences were noted in other measured variables (heart rate, respiratory rate, oxygen saturation, transcutaneous carbon dioxide level, rectal temperature, global skin temperature, core temperature, and subjective perceptions) between controls and FFRs and between FFR models.

Conclusion: After 1 hour of exercise in hot, humid ambient conditions, P100 FFRs retained better fit than N95 FFRs, without additional physiologic or subjective impact. Wearing FFRs under these conditions does not add to the body's thermophysiologic or perceptual burdens.

Published by Elsevier Inc. on behalf of the Association for Professionals in Infection Control and Epidemiology, Inc.

Filtering facepiece respirators (FFRs) are worn to prevent the inhalation of toxic and infectious airborne particles. The National Institute for Occupational Safety and Health (NIOSH) certifies FFRs and classifies them according to 3 letter designations that refer to the respirator's oil resistance (N [not resistant], R [somewhat resistant], and P [strongly resistant]) and 3 numerical designations (95, 99, and 100) that indicate the percent filtration efficiency of the respiratory filter.[1] Employers mandated by the U.S. Occupational Safety and Health Administration (OSHA) to provide respiratory protection in the form of FFRs are required to provide employee fit testing (qualitative or quantitative) annually to ensure that the FFR fits the user appropriately to provide the expected level of protection.[2] In ambient conditions of high heat and humidity, there is concern that FFR moisture accumulation from the combined effects of ambient humidity, retained moisture from the exhaled breath, and facial sweat accumulation can result in a loosening of the seal of the FFR to the face (with resultant ingress of contaminants) and a potential increase in breathing resistance as a result of blockage of pores in the FFR filter that could increase the work of breathing.[3,4] In recent years, these concerns have been amplified in relation to highly publicized environmental events (eg, Gulf oil spill on the Louisiana coast) and infectious disease outbreaks (eg, Ebola, Middle East respiratory syndrome) associated with the use of respiratory protective equipment in hot and humid environments. This study was undertaken to evaluate the effect of a hot, humid environment on the fit of class N95 FFRs, the most widely used FFR in industry and health care, and on class P100 FFRs used for protection from toxic airborne particulates in an industrial environment where oil may be encountered. A secondary objective of the study was to

* Address correspondence to Raymond J. Roberge, MD, MPH, National Personal Protective Technology Laboratory, 626 Cochrans Mill Rd, Pittsburgh, PA 15236.
E-mail address: dtn0@cdc.gov (R.J. Roberge).

Funding/Support: Supported by National Personal Protective Technology Laboratory internal operating funds.

Disclaimer: The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health. Mention of product names does not constitute endorsement by the authors or the National Institute for Occupational Safety and Health.

Conflicts of interest: None to report.

0196-6553/$36.00 - Published by Elsevier Inc. on behalf of the Association for Professionals in Infection Control and Epidemiology, Inc.
http://dx.doi.org/10.1016/j.ajic.2015.08.027

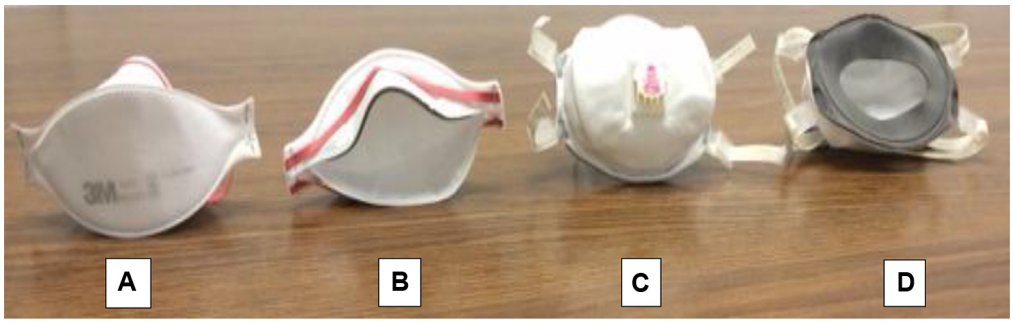

Fig 1. Anterior and posterior views of 3M model 1870 N95 filtering facepiece respirator (A and B) and 3M model 8293 P100 filtering facepiece (C and D).

determine any differences in physiologic and subjective responses between the N95 and P100 classes of respirators in the aforementioned ambient environment.

MATERIALS AND METHODS

Twelve healthy, nonsmoking men were recruited for the study. Subject mean demographics were as follows: age was 23.5 ± 1.6 years, height was 181 ± 6 cm, weight was 81.8 ± 8.1 kg, and body mass index was 24.9 ± 2.3 kg/m^2. The study was approved by the NIOSH Institutional Review Board, and all subjects provided written and verbal consent. Prior to exercising, subjects were first instrumented with a 4,600 Precision rectal thermistor (YSI Temperature, Dayton, OH) for core temperature monitoring, wired skin sensors (Grant Industries, Surrey, UK) for skin temperature measurements at 4 sites (shoulder, chest wall, thigh, and calf) to determine mean global skin temperature,[5] 2 wireless iButton sensors (Maxim, San Jose, CA) for facial skin temperature and respirator microenvironment (ie, respirator dead space, identified as the airspace between the respirator's internal surface and the wearer's face that is not occupied by any part of the facial anatomy) temperature and humidity measurements, a Tosca (Radiometer America, Westlake, OH) combination pulse oximeter-transcutaneous carbon dioxide sensor attached to an earlobe for pulse-derived oxygen saturation (SpO_2)—transcutaneous carbon dioxide ($tcpCO_2$)—heart rate (HR) monitoring, and a BioHarness physiologic monitoring chest strap (Zephyr, Annapolis, MD) for respiratory rate (RR) determination.

Subjects were given instructions in donning FFRs, performed negative and positive user seal checks to assess the seal of the FFR to the face,[2] and then underwent respirator quantitative fit testing of a 3M model 1870 N95 FFR (3M, St Paul, MN) with the PortaCount Plus Model 8020. Fit testing of the N95 FFR was carried out with the N95-Companion Model 8095 fit tester (TSI, Shoreview, MN), a condensation nucleus particle counter that measures the concentrations of ambient particles outside and inside the FFR during successive 1-minute OSHA standard exercises (normal breathing, deep breathing, head movement side-to-side, head movement up and down, talking out loud, bending over, and normal breathing) and one 15-second exercise (grimace) that is not included in the calculation of the fit factor.[2] The fit factor is the ratio of the outside and inside particles and is calculated as follows:

$$FF = \frac{(Cb + Ca)}{2Cr}$$

where *FF* is the fit factor, *Cb* is the particle concentration in the ambient sample before the respirator sample, *Ca* is the particle concentration in the ambient sample after the respirator sample, and *Cr* is the particle concentration in the respirator sample. The subjects then donned a 3M model 8293 P100 FFR (3M, St Paul, MN), adjusted the straps, and underwent quantitative fit testing using the PortAcount Plus Model 8020 (the N95 Companion is not used for P99 and P100 respirators). Fit factors with the PortaCount with N95 Companion are normally reported up to 200, and if they surpass this level, they are reported as 200+ because they exceed the manufacturer's recommended operating range,[6] whereas the PortaCount Plus can record fit factors as high as 10,000 (for ease of data comparisons between the N95 FFR and P100 FFR in the current study, scores >200 for the P100 FFR were recorded as 200+). A passing score on an OSHA quantitative fit test is ≥100, indicating ≤1% penetration of particles into the dead space of the respirator. The 3M 1870 N95 FFR and 8293 P100 FFR models (see Fig 1 and Table 1 for FFR features) were fit tested immediately before (preexercise) and after (postexercise) 1 hour of treadmill walking (5.6 km/h, 0° incline) in an environmental chamber with ambient conditions of 35°C and relative humidity 50% (equivalent to a heat index of 40.7°C).

Table 1
Filtering facepiece respirator features

Parameters	3M 1870 N95 FFR	3M 8293 P100 FFR
Sizes available	Standard	Standard
Shape	Flat fold	Cup
Dimensions (cm)	21.0 × 23.8 × 8.6	20.3 × 26.6 × 5.0 cm
Weight (gm)	9.3	29.3
Exhalation valve	No	Yes
Tethering devices	Two narrow, nonadjustable polyisoprene bands	Two adjustable, wide, braided polyester straps with multiple parallel polyisoprene bands
Layers	Three hydrophobic layers	Three hydrophobic layers
Other features	Pliable nose bar	Pliable nose bar, inner foam face seal
Static dead space volume (mL)	325	240
Filter resistance (mm H_2O)*	6.3 ± 0.5	17.4 ± 0.8

FFR, filtering facepiece respirator.
*Measured at 85 L/min of constant airflow.

Three randomly allocated exercise sessions were carried out on separate days: 2 sessions involved wearing either model of FFR, and 1 involved a control session (no FFR). Subjects were not allowed to make any adjustments to the respirators after the initial adjustment just prior to the pre-exercise fit test, so the postexercise fit test reflected only the impact of the exercise and environment. All fit testing was performed outside of the environmental chamber. During the treadmill exercise, subjective measurements were taken at baseline and then every 20 minutes using visual analog numerical scales for exertion (Borg Rating of Perceived Exertion Scale, a 15-grade scale ranging from no exertion at all to maximal