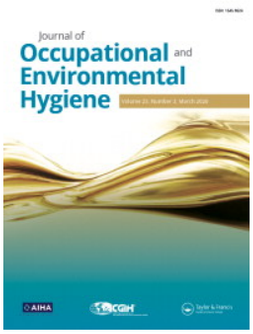

Journal of Occupational and Environmental Hygiene

ISSN: 1545-9624 (Print) 1545-9632 (Online) Journal homepage: www.tandfonline.com/journals/uoeh20

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To cite this article: Jenna L. Gibbs, Brooke Vollmer, Carolyn E. Sheridan, Kent Pinkerton, Renee T. Anthony, Stephanie Holm, Catherine Karr, Anna Proctor & Andrea Swenson (2026) Filtering facepiece respirator use among farm youth in the US: A review, Journal of Occupational and Environmental Hygiene, 23:3, 178-190, DOI: 10.1080/15459624.2025.2589137

To link to this article: https://doi.org/10.1080/15459624.2025.2589137

JOURNAL OF OCCUPATIONAL AND ENVIRONMENTAL HYGIENE
2026, VOL. 23, NO. 3, 178–190
https://doi.org/10.1080/15459624.2025.2589137

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REVIEW ARTICLE

Filtering facepiece respirator use among farm youth in the US: A review

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ABSTRACT

The COVID-19 pandemic underscored the critical need for protective equipment, such as filtering facepiece respirators (FFRs), particularly for youth. This systematic review addresses the significant gap in evidence-based guidance for FFR use among US farm youth, a group potentially exposed to diverse respiratory hazards. Current FFR designs and protocols for FFR use are largely adult-centric. Adhering to PRISMA 2020 guidelines, a multidisciplinary panel reviewed 31 publications published between 1990 and 2023. An independent working group of agricultural safety professionals also contributed by reviewing procedures and publications to check for bias during the review process. Key findings show that while FFRs appear physiologically tolerable by youth study subjects. Subjective discomfort and poor fit of adult-sized respirators remain major barriers to effective use and compliance. Studies highlight the critical need for youth-specific FFR designs based on detailed facial anthropometrics and the development of standardized fit-testing protocols tailored for growing youth. Furthermore, evidence-based guidance on ethical pediatric medical evaluations for respirator use and targeted respiratory health education are urgently needed. This review emphasizes that a concerted effort from manufacturers, researchers, and regulatory bodies is essential to ensure youth on farms can safely use respiratory protection.

KEYWORDS

Agriculture; anthropometrics; FFR; N95; pediatric; personal protective equipment (PPE)

Introduction

The SARS-CoV-2 (COVID-19) pandemic significantly increased the public's reliance on protective equipment, including items like face coverings, masks, and filtering facepiece respirators (FFRs). While FFRs offer protection against respirable particulate matter compared to "masks" (OSHA 1998), widespread confusion emerged regarding their proper application, particularly for youth. This is relevant for youth engaged in agricultural work in the US, a population routinely exposed to diverse respiratory hazards such as pesticides, animal byproducts, and particulate matter through both occupational and leisure-based activities. As the most hazardous industries for youth workers, agriculture lacks some protections found in other sectors due to exemptions in the Fair Labor Standards Act (FLSA) (Iannacci-Manasia 2023; US DOL 2024).

Current regulatory frameworks and FFR designs in the US, including approval processes conducted by the National Institute for Occupational Health and Safety (NIOSH) and fit-testing protocols accepted by the Occupational Safety and Health Administration (OSHA) for respirator use in workplace settings, are predominantly organized for adult occupational settings, leaving a critical gap in evidence-based guidance for youth/pediatric FFR use (Part 84—Approval of Respiratory Protective Devices 1995; Zhuang et al. 2005, 2007; Zhuang and Bradtmiller 2005; ASTM International 2021, 2022; NIOSH 2024).

NIOSH's respirator approval program ensures NIOSH-approved respirators provide a specific level of respiratory protection by meeting the performance standards defined in the US Code of Federal Regulations for approving respiratory protective

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/15459624.2025.2589137. AIHA and ACGIH members may also access supplementary material at http://oeh.tandfonline.com.

devices, known as 42 CFR Part 84. However, NIOSH does not conduct a formal fit evaluation for FFR approval, since no standardized fit-testing strategy is included in the current regulations. A key gap is that manufacturers of FFRs are not currently required to independently assess fit on a range of human faces as part of the approval. It is likely that this problem is exacerbated for youth, who represent a segment of the population whose smaller and developing facial dimensions may not be adequately accommodated by current FFR design. This systematic review aims to summarize existing research to identify the current research needs for evidence-based guidance for FFR use as it pertains to farm youth, and to establish a clear path for future investigations on the sensitive topic.

At the time of this publication, the lack of youth-specific FFR designs, respirator fit-testing protocols (for youth), and tailored guidance may contribute to inadequate respiratory protection for farm youth, potentially exposing them to significant health risk—whether the respiratory hazards are occupational or leisure. This may be exacerbated by the fact that many farms in the US are exempt from formal OSHA inspections, particularly those with fewer than 10 employees (OSHA 1998). Gibbs et al. (2025) describe how US-based farms may also rely on unpaid family members and youth who may not fit the standard employee definition for regulatory purposes. Some more regulated tasks, such as those that involve commercial or private agricultural pesticide application, require the individual to be at least 16–18 years old, depending on requirements (WPS; 40 CFR 170.507(b)(10)), but the NIOSH certification would not apply to such age groups.

Given the importance of using certified respiratory protection, it's crucial to note the performance differences among FFR types. Previous research identifies N95 respirators as the preferred type for most farm tasks (Popendorf et al. 1995). Other FFRs, such as KN95s, have performed poorly in NIOSH assessments when compared to N95s. This discrepancy is likely due to differences in the testing and approval processes. Even though N95s aren't currently evaluated by NIOSH for youth, they are likely to be preferred over the use of KN95s or other non-certified FFPs (NIOSH 2020).

The Agricultural Youth Worker Guidelines (AYWG), initially established in the 1980s, currently recommends respirators as a protective strategy for 22 of 53 listed farm tasks (which may be occupational or chore-based) for youth, serving as guidance for supervisors and parents for appropriate protective equipment during ability-appropriate tasks. The AYWG are not regulatory but were developed with the Fair Labor Standards Act (FLSA) regulations in mind, providing a detailed framework to match youth's abilities to a given task (US DOL 2024). With increasing wildfires and natural disasters, respiratory protection may also become essential for outdoor activities. On many farms, operations (and tasks) continue despite natural disasters. This review of existing literature on FFR use in youth reveals some patterns of physiological impacts, physical respirator fit challenges, filtration effectiveness, and factors influencing compliance, thereby informing the development of better future investigations of this potential protective strategy for farm youth.

Methods

To ensure a transparent and rigorous systematic review process, we adhered to the PRISMA 2020 statement by Page et al. (2021). The review focused specifically on the safety and efficacy of FFR use among youth, with discussions and recommendations tailored to farm youth. In this review, "youth" was defined as individuals 18 years old or younger and focused on a subset of the youth working and living on farms. As a systematic review of existing literature, this study was deemed exempt from Institutional Review Board (IRB) approval. A glossary of terms used in this study has been provided in Table 1.

A multidisciplinary academic panel, comprising eight researchers, guided the study. This panel included experts in pediatric environmental health, industrial hygiene, respirator fit/performance, facial anthropometrics, wildfire smoke/air pollution exposure, and farm youth health and safety. The panel convened twice in 2024 to collaboratively develop search terms, define PICO-guided inclusion and exclusion criteria (see Table 2, Eriksen and Frandsen 2018), and establish scoring protocols for study quality. The panel decided to focus on filtering facepiece respirators (FFRs), such as N95 and KN95 (or similar models with reusable parts), used by children and young adults to filter particulate matter and aerosols, while excluding studies on adults or those using facial coverings or surgical masks (Table 2). No panel member reviewed or scored papers with a conflict of interest (e.g., authorship or collaboration). The lead author leveraged individual panel expertise during the scoring phase in adherence to PRISMA guidelines. All study types were considered for inclusion, including original research articles, case reports, commentaries/editorials, short research reports, and other reviews, as this is an

Table 1. Glossary of terms.

Term	Description
ASTM (American Society for Testing and Materials)	Located in the US, considered an organization that develops and publishes voluntary standards for products like respiratory protection.
FFR (Filtering Facepiece Respirator)	A type of tight-fitting respirator that filters airborne particles, often referred to by certification standards such as N95 or N99.
OSHA (Occupational Safety and Health Administration)	US government agency that sets and enforces workplace health and safety standards, including those for appropriate respiratory protection.
NIOSH (National Institute for Occupational Safety and Health)	US federal agency responsible for conducting research and making recommendations for the prevention of work-related injury and illness, including the approval and certification of respirators.
FLSA (Fair Labor Standards Act)	A US federal law that establishes minimum wage, overtime pay, and record-keeping standards, with specific regulations for youth workers.
AYWG (Ag Youth Worker Guidelines)	A non-regulatory framework that provides guidance for supervisors and parents on appropriate protective equipment (like respirators) and age-appropriate tasks for youth on farms.
ISASH (International Society of Agricultural Safety and Health)	An international professional society focused on safety and health in agricultural contexts, including forestry and fishing.

Table 2. Study inclusion and exclusion criteria.

Inclusion	Exclusion
Population	
Pediatric: Included children, youth, young adults, or individuals with small facial sizes indicative of US youth facial sizes.	**Adult:** Focused only on adult populations, such as health care workers during the COVID-19 pandemic, without mention of small facial sizes or FFR use for children or young adults.
Humans: Involved (or make recommendations for) humans.	**Materials science:** Examined or described features of FFP filtration material with no relevance to respiratory protection.
Intervention	
FFR Focus: Must include filtering facepiece respirators (FFRs), including N95, KN95, and other approved type with US or international approvals. FFRs must be used for filtering particulate matter or aerosols, not for other purposes (e.g., prevention of splash).	**Lacked FFR Focus:** Many studies addressing youth protective equipment during the COVID-19 pandemic were focused only on protective cloth facial coverings or surgical "masks" that are not adequate for protection against most airborne hazards in agriculture.
FFR Use and Effectiveness: Evaluated the use, safety effectiveness, perceptions, and/or adherence to FFRs in the target population.	**FFR Use for Other Purposes:** Examined FFRs but not for filtering particulate matter or aerosols.
Outcome	
The study evaluated the use, safety, guidance, and adherence to FFRs in the target youth population.	Focused only on protective cloth facial coverings, surgical masks, or unidentified "masks" without FFR designation that were adequate for protection against most airborne hazards in agriculture. Studies examining FFRs for use against COVID-19 spread or droplets but not for filtering particulate matter or aerosols. Studies are irrelevant to human respiratory protection.

emerging and sensitive topic where comprehensive data is still developing.

To identify relevant studies on the effectiveness of FFRs in youth, the comprehensive search strategy was executed across five major electronic databases: PubMed, EMBASE, Scopus, CINAHL, and Web of Science. Search terms were meticulously crafted to capture relevant literature on youth age groups (e.g., juvenile, child, adolescent, teen, youth, pediatric, pediatrician) and filtering facepiece respirators (e.g., N95 respirators, N95, KN95, KN 95, N94, KF94, KF 94, FFP2, FF P2, FFP 2), including variations (e.g., uncapitalized) of these terms. At the time of this publication, KN (China), KF (Korea), and FFP (European Union) respirators are not approved for use in US

workplaces. All studies published in English (or English translated) between 1990 and 2023 were considered, yielding a pool of 1,484 records. The study selection process involved a rigorous three-stage screening protocol utilizing Rayyan, a platform designed for systematic review management. Initial records were deduplicated, resulting in 686 articles. Two independent reviewers from the academic panel screened titles and abstracts against the predefined inclusion and exclusion criteria based on the PICO framework identified by the panel. A third reviewer performed quality control by screening a subset of 40 articles, achieving an inter-rater agreement of 95%, which indicated high consistency. Discrepancies were resolved through reviewer discussion.

This stage identified 81 articles for full-text screening. Full-text articles were screened by two independent reviewers, and 54 additional articles were excluded. The most frequent reasons for exclusion were a sole focus on non-respirators during COVID-19 (e.g., surgical masks, facial coverings) or a lack of specific focus on youth or individuals with small facial dimensions. Additionally, two relevant studies were identified through a manual review of references during the full-text screening. Following this comprehensive process, 31 studies were ultimately included in the systematic review. The detailed selection process is

visually represented in a PRISMA diagram (provided in Supplemental Material).

Data extraction used a mixed-methods approach with the entire academic panel. A minimum of two reviewers were assigned for comprehensive evaluation for all included publications, with a third reviewer added if significant score discrepancies were found. Reviewers assessed the scientific methodological rigor of each study using a five-point scale and written feedback, with guidelines based on a published Rigor and Transparency Index Metric for reviews (Menke et al. 2020). A three-point scale was used to assess the generalizability of each study's findings to the target population of youth working in US agriculture. The primary author double-checked all completed reviews to ensure consistency and check for bias. The five-point methodological rigor scale and the three-point generalizability scale are provided in Supplemental Material. A secondary, exploratory analysis was conducted utilizing Rayyan's AI tool to assess paper quality, bias, and inclusion based on appropriate search terms. This AI tool employed natural language processing algorithms and was stated to prioritize papers meeting the inclusion criteria. The AI tool scores were not consistently aligned with human review, and thus, its assessment was not used to determine the level of emphasis given to papers in the findings and discussion sections. At the time of this publication, most AI platforms have not been found to be entirely reliable without human review (Blaizot et al. 2022). The authors intentionally included the results from the Rayyan AI tool's assessment to highlight this comparison.

All reviewers provided written text summaries highlighting key research needs and findings most pertinent to youth working and living in agricultural areas. This feedback was collected via Google Forms, and RQDA (RStudio 2024.04.2) was used to import text from the reviewers and systematically code themes from reviewer text. The primary author organized these themes into major findings for the discussion section, ensuring the synthesis examined the findings through the lens of youth working in agriculture. To assess the overall quality of the 31 studies, a composite score was calculated for each paper by summing its scientific rigor and generalizability scores (maximum of 8). Reviewer forms and criteria used for assessing scientific rigor, generalizability, and qualitative feedback are provided in Supplemental Material.

Additional stakeholder input was gathered at a one-hour Working Group on Youth Respirators, convened at the 2024 International Society for Agricultural Safety and Health (ISASH) Conference in Portland, Oregon. Fourteen members contributed their perspectives via Mentimeter, an interactive polling tool. Eleven of these 14 working group participants were not involved in the initial screening, scoring, or review of the papers, providing an additional independent assessment of the thematic grouping and overall synthesis. The Working Group members provided input on the thematic grouping of the 31 publications, which included health impacts, respirator fit and design, general pediatric respirator guidance, filtration efficiency, SARS-CoV-2 exposure, and youth respiratory protection behavior and compliance. Participants identified concerns related to youth respirator use on farms and discussed specific research gaps within the agricultural context.

Results

This systematic review synthesized findings from 31 identified publications examining FFR use by youth or individuals with smaller face sizes. The publications are listed in Table 3 and were categorized into six themes: health and physiological impacts, fit and design, general guidance, respirator filtration efficiency, disease transmission, and compliance. For conciseness, findings related to respirator fit, design, and filtration efficiency were combined into a single section, as were general review, guidance, and youth compliance. Two studies specifically assessing SARS-CoV-2 disease transmission were reviewed, with limited capacity due to their limited relevance to the broader agricultural context of this specific review.

Health and physiological impacts of youth wearing FFRs

Eleven publications investigated the potential health effects experienced by youth when wearing FFRs. While FFRs are effective in protecting against respiratory exposures, concerns have been raised regarding potential elevations of CO_2 levels within the respirator's dead space, with some speculation about impacts on brain development, memory, and learning in young wearers (Lubrano, Bloise, et al. 2022; Kisielinski et al. 2023). Most studies examined respirators traditionally designed and approved for adults, often by modifying adult-sized respirators (e.g., tucking edges, adjusting ear loops) to achieve a better seal on youth test subjects instead of testing youth-specific respirators (Lubrano et al. 2021). Most studies found no to very little significant adverse effects on youth heart rate, oxygen saturation, or respiratory rate, even during moderate physical activity like brisk treadmill

Table 3. Included studies and key characteristics.

Publication (Author, Year)	Shortened title	Description: Short abstract	Description: Age (Range)	Inclusion AI tool (✓) = yes (-) = no	Reviewer scores* Methodological rigor (of 5)	Reviewer scores* Generalizability (of 3)	Composite score (of 8)
Health and Physiological Impacts of Wearing Pediatric Respirators ($n = 11$)							
Lubrano 2021	Effects N95 mask pulmonary function children	Compared effects of FFRs with and without exhalation valves on respiratory function in 22 children	3-12 years	✓	4	3	7
Happernegg and Kerbl 2023	Influence of FFP2 on physiological parameters in children	FFRs increased inhaled and exhaled CO_2 levels in 15 children but did not significantly influence blood gases or hypercarbia	6-17 years	✓	4	2	6
Weigelt et al. 2023	Sports despite masks: no negative effects of FFP2 on cardiopulmonary exercise in children	Examined effects of FFP2/N95 masks on the cardiopulmonary capacity of 20 children during treadmill exercise	8-10 years	✓	4	2	6
de Yzaguirre i Maura et al. 2021	Cavitary air inspired through a mask in competitive adolescent athletes	Investigated carbon dioxide levels during exercise in 46 adolescent athletes operating at high capacity with FFRs. Approximately one-third exceeded a 2% carbon dioxide threshold	13-17 years	–	2.5	3	5.5
Walach et al. 2022	CO_2 rises beyond acceptable safety levels in children under mask	Examined how wearing FFP2/N95 masks can impact carbon dioxide levels in inhaled air for 45 children	6-17 years	✓	2.5	3	5.5
Kisielinski et al. 2023	Toxicity of chronic CO_2 exposure associated with face mask use, in pregnant women, children - scoping review	Scoping review of 43 publications, suggested that FFRs can elevate inhaled CO_2 levels, potentially exceeding recommended limits and posing risks to vulnerable groups.	Not specified ('pregnant women, children, adolescents')	✓	1	3	4
Lubrano, Bloise et al. 2022	Cardiorespiratory function in overweight/obese children wearing masks	Examined if FFR use was associated with respiratory distress in 29 children	6-17 years	✓	1.5	1.5	3
Martellucci et al. 2022	Inhaled CO_2 while wearing masks: a pilot study	Investigated the effects of wearing FFP2 respirators on inhaled CO_2 concentration in 146 healthy individuals	10-90 years	–	1.5	1	2.5
Eberhart et al. 2021	Impact of face masks on children - mini review	Reviewed two studies and suggested that 'masks' do not significantly compromise ventilation or oxygen intake in health individuals and more research is needed	0–18 years*	–	0.5	1	1.5
Lubrano, Ventriglia, et al. 2022	Safety of face masks in pediatric age	Revoked previous study's conclusion (Martellucci et al. 2022)—that mask guidelines should be reevaluated because masks increase inhaled CO_2 to unsafe levels—is inaccurate	0–18 years*	–	0.5	0.5	1
Lubrano 2023	Respiratory function children wearing masks	Letter to the editor, revokes paper by Walach et al. (2022) that claimed that face masks were dangerous for youth due to CO_2 levels in air	0–18 years*	–	0.5	0.5	1
Fit and Design of Pediatric Respirators ($n = 8$)							

Čuta et al. 2024	Fit and design of filtering half-mask for sub-adults	Used 3D face models of 1,137 subadults to assess the fit of a 3D FFR	4-18 years	✓	5	3	8
Khairul Hasni et al. 2023	Effect of N95 designs on respirator fit and association with gender/facial dimensions	Investigated design of 6 NIOSH-certified N95 respirators effect on fit while examining associations with facial size/gender among 135 individuals	18-70 (included small face sizes)	✓	4	1	5
O'Kelly et al. 2023	Fit of N95s and KN95s, accuracy of fit checking	N95 respirators offered protection against aerosols in a group of 7 tested individuals, but fit tests were crucial, fit checks were unreliable	17-74	✓	3	2	5
Lin and Chen 2017	Small-to-medium head and face dimensions for developing respirator fit test panels and evaluating fit of FFPs	Developed and evaluated respirator fit test panels (using 206 young adults) for small-to-medium facial features and found that respirator fit improved with larger facial dimension	21-30 years (included small face sizes)	–	4	1	5
Yu et al. 2014	Fit of N95s used widely in China	Investigated the effectiveness of 10 widely used N95s in China and found overall poor fitting characteristics, particularly for those with small face dimensions	(>18 years) (no data provided) Mean age, 25 years	–	3	1	4
Brosseau 2010	Fit testing respirators for public health emergencies	Examined if two N95 respirators could meet criteria for public health emergency respirators by measuring the quantitative fit factors of the respirators on 35 completely untrained and inexperienced participants	18-34	–	3	0.5	3.5
Suryawanshi, et al. 2023	Face mask wearing image dataset: image-based face mask detection models	Created a dataset of ~25,000 images of individuals wearing face masks correctly and incorrectly, categorized by mask type, age, and gender	None specified	–	1	1	2
Lei et al. 2014	Determining contact area between a respirator and headform	Presented the validation of a novel computer-based method to determine contact area of a human face and N95 respirator. Among the headform sizes tested, the "medium" size headform had the most contact area, with "large" and "small" headforms reporting significantly less.	None specified (included small headforms)	–			
General Review/Guidance for Youth Respirator Use ($n = 4$)							
Holm et al. 2021	Health effects of wildfire smoke in children: a narrative review	Suggests that a small, properly fitted FFR would offer protection against wildfire smoke for children who must be outdoors, decreasing exposure by an estimated 80%	0–18 years*	✓	4	3	7
Li et al. 2021	What we are learning from COVID-19 for respiratory protection issues	Review on respiratory infectious diseases and FFR, finds that children are generally less protected than adults due to issues with fit and proper wear, although they still benefit from wearing	Not specified	–	4	1.5	5.5
Slavik et al. 2023	Educating families about wildfire smoke and children's health: healthcare professionals	Healthcare professionals should advise parents to use FFR for 'older children' to reduce their wildfire smoke exposure	0–18 years*	✓	2	3	5
Bhardwaj and Thompson 2022	Why wear a mask? Explaining masking to children	Educated parents on the importance of mask use for children in the pandemic context,	2-18 years	–	1.5	1	2.5

(*Continued*)

Table 3. Continued.

Publication (Author, Year)	Shortened title	Description		Inclusion AI tool (✓) = yes (-) = no	Reviewer scores*		Composite score
		Short abstract	Age (Range)		Methodological rigor (of 5)	Generalizability (of 3)	(of 8)
		described challenges of children's consistent use					
Filtration Efficiency of Filtering Facepiece Respirators ($n = 4$)							
Guha et al. 2015	Effectiveness of pediatric facemasks for protection against submicron-sized aerosols	N95 FFRs offer low penetration rates of submicron-sized aerosols at flow rates representative of children activities	Not specified (examined 'facemasks designed for children')	✓	4	3	7
Seo et al. 2023	Filtration efficiency and pressure drop of school-aged children's masks at varying face velocities	Nonwoven mask types (like FFR) showed increased filtration efficiency at lower simulated face velocities representative of children's breathing and are superior when compared to woven types	0–18 years (N95 style masks tested on youth ≥10 years)	✓	4	2	6
Goh et al. 2019	Clinical trial evaluating safety, fit, and comfort of a novel pediatric respirator	Examined the safety, fit, and comfort of a novel FFR (AIR+ Smart Mask, FFP2) on 106 children and found it was well-fitting, comfortable, and safe for use in mild exertion	7-14 years	✓	4	1.5	5.5
Linšak et al. 2023	Bacteria filtration efficiency for children's protective face masks	Examined the bacterial, yeast, and mold filtration efficiency of FFP2 masks using air samples from children in kindergarten and primary school settings	Kindergarten-primary school (age not specified)	–	3	2	5
Youth Respirators to Reduce Disease Transmission ($n = 2$)							
Jarnig et al. 2022	Wearing FFP2 masks in classrooms	Mandatory FFP2 respirator use in school classrooms reduces SARS-CoV-2 transmission among 614 secondary school students	10-20 years	✓	2.5	2	4.5
Cuesta-Zigorraga et al. 2023	Nurse-led education to improve COVID-19 prevention knowledge among adolescents	As part of a training program with 520 adolescents during COVID-19, educators presented FFRs as one of three of effective facial coverings and concluded that respirator specific training was necessary with youth	12-17 years old	–	1	1	2
Youth Respirator Compliance (Behavioral/Psychological) ($n = 2$)							
Preest et al. 2024	Children's experiences of mask wearing: A systematic review	Synthesized findings from 45 studies on children's mask wearing experiences in various contexts and found that children reported discomfort from improper fit and heat, struggle with communication, although most masks were safe for wear	4-14 years	–	4	2	6
Reszke et al. 2021	Face mask use of young Polish during the COVID-19 epidemic	Surveyed 1,173 young people wearing face masks, including FFRs in mandatory situations. Respondents with atopic predisposition or sensitive skin reported less use of masks	17-27 years	✓	4	1	5

walking (Goh et al. 2019; Lubrano et al. 2021; Weigelt et al. 2023; Happernegg and Kerbl 2023). A particularly relevant study by Weigelt et al. (2023), involving elementary-aged youth (8–10 years), reported some physiological changes, such as increased respiratory effort and slightly lower oxygen levels, during physical activity with FFP2 respirators, but did not observe significant negative health outcomes. One study (Walach et al. 2022, since retracted) reported significantly higher CO_2 levels and claimed links to short-term effects like headache, concentration, and fatigue. Other researchers found that the authors of the paper used an inaccurate and subjective measurement method and made incorrect comparisons by applying indoor air quality and occupational exposure limits to breathing-zone measurements, with more details provided on their reasoning (Lubrano et al. 2023; Steinle and Koller 2023). In the other publications, subjective perceptions were reported by youth, including reports of "discomfort" and "shortness of breath." However, these studies reported a subsiding of these perceptions over time as the youth adapts (Happernegg and Kerbl 2023; Preest et al. 2024).

Research needs:

- Development of procedures for pediatric medical evaluation and respirator fit testing before youth FFR tests. If procedures differ from those for non-pediatric populations (such as adults) and are applied to workplaces, they would need to be incorporated into the OSHA Respiratory Protection Standard (OSHA 1998), as many youths in the US are employees and may be subject to OSHA.
- Research on relevant health effects (such as CO_2 exposure and cardiopulmonary workload) with more youth-specific FFRs (valved and non-valved) instead of modified adult FFRs at representative physical activity levels.

Fit, design, and filtration efficiency of FFRs worn by youths and small faces

Eight publications examined respirator fit in populations including youth and adults with "small face sizes" indicative of youth based on facial anthropomorphics (Chvatal et al. 2005; Mellion et al. 2013). Only one study focused exclusively on youth (ages 4–18 years) and evaluated the fit of a reusable, 3D-printed half-mask, likely a hybrid model, on 1,137 digital 3D models (Čuta et al. 2024). This study revealed that an initial adult-oriented 3D mask design poorly fitted many youth, necessitating new sizing the proposals of four sizing categories based on more variation. This study received a high composite score and called for more youth-specific respirator designs accounting for variability.

Other studies generally focused more on adult participants (some categorized with 'small' face sizes) but also included some youth aged 17 or older (Lei et al. 2014; Yu et al. 2014; Lin and Chen 2017; Khairul Hasni et al. 2023; O'Kelly et al. 2023). These studies demonstrated varying fit-test passing rates across different N95 FFR models, with certain models fitting participants better, depending on face size and dimensions (Khairul Hasni et al. 2023, O'Kelly et al. 2023, Lin and Chen 2017). Lei et al. (2014) utilized a computer algorithm to simulate respirator donning on various headforms, finding that smaller headform sizes achieved less facial contact area, suggesting that some N95 FFRs may not adequately fit individuals with smaller faces. This further supported the findings of Čuta et al. (2024), who found that adult-sized respirators were a poor fit for many youths with smaller facial forms. The collective results emphasized the importance of the development of respirator fit-testing procedures to ensure optimal protection from tight-fitting respirators (Yu et al. 2014; Khairul Hasni et al. 2023; O'Kelly et al. 2023).

Four publications specifically examined FFR filtration efficiency in youth wearers. These studies, primarily assessing adult FFRs worn by youth, indicated that filtration efficiency might be slightly higher in youth due to their lower face velocities (Seo et al. 2023). This is a critical finding because, while respirators are certified at a standard test flow rate of 85 L/min to ensure performance at high-end rates (to challenge the filter condition in a "worst-case" scenario), youth typically have much lower average and peak breathing rates than adults, even during strenuous activity (42 CFR, Part 84). These differences in breathing rates also apply to individuals of differing body size and activity levels.

Although the 85 L/min test flow is necessary to confirm filter performance under high-flow conditions, the actual breathing rates for most adults rarely approach this (except during the most strenuous work), and breathing rates for youth are generally lower than adults across comparable activity levels. Guha et al. (2015) found that adult N95 FFRs maintained low penetration values ($\leq$5) against submicron particles at flow rates lower than 85 L/min (10, 30, and 70 L/min), which better represent youth activity levels, confirming their filtration efficiency. Non-

woven materials, common in FFRs, generally exhibited higher filtration efficiencies than woven materials (Linšak et al. 2023; Seo et al. 2023). While one study reported reduced SARS-CoV-2 transmissions in school-aged children using adult-sized FFRs, it was limited by the absence of youth-specific respirator designs and lack of fit testing (Jarnig et al. 2022).

Research needs:

- Population-based anthropometric surveys for youth head and facial measurement data specific to the development of youth bivariate facial panels to inform the development of headforms used for advanced or rapid testing of youth-specific FFRs. Comparison of previous studies' "small headform" sizes to true youth facial dimensions from anthropometric surveys.
- Development of youth-model respirator certification testing protocols accounting for differences in flow rate and bivariate facial panels.
- Development of respirator fit-testing protocols for youth and research on how those may differ from adult protocols.

General review and guidance for youth FFR use and compliance

Four publications offered review-based recommendations for FFR use by youth, acknowledging benefits and challenges. None of these studies discouraged FFR use and often highlighted potential benefits such as protection from wildfire smoke or pollution exposure (Bhardwaj and Thompson 2022, Holm et al. 2021, Li et al. 2021, Slavik et al. 2023). Consistent with other findings, these reviews discussed the disparity in the availability of youth-specific FFRs. These publications also discussed the importance of respirator comfort for youth compliance. The studies found that youth often complained about breathing resistance, facial pressure, heat buildup, and strap discomfort. Two studies advocated for the development of youth-specific respirator training and education programs (Holm et al. 2021; Li et al. 2021).

Two publications specifically investigated FFR acceptance among youth and found that youth (and their parents) are more likely to use FFRs if they receive education on why they are necessary (Preest et al. 2024, Reszke et al. 2021). Preest et al. (2024) observed that while youth frequently reported initial discomfort with FFRs, their acceptance and subsequent use increased when they understood the necessity of wearing them and when adults (such as parents) modeled appropriate FFR use behavior.

Research needs:

- Long-term development of respiratory health education and training for healthcare professionals is crucial, as they are often trusted sources of health and safety information within agricultural communities (Chiu et al. 2015). This training should be tailored to FFR recommendations and guidance for youth. These efforts should also be expanded to include parents, schoolteachers, and other supervisors of farm youth, who play a critical role in promoting and ensuring safety. Further evaluation of social and behavioral factors influencing youth FFR use, including comfort and social pressures.

Discussion

This systematic review has further highlighted a critical gap in evidence-based guidance and regulation for filtering facepiece respirator (FFR) use among youth working in US agriculture. At the time of this publication, most previous studies have focused on adult occupational respiratory protection, with limited research specifically addressing the physiological and anatomical characteristics of growing youth, particularly in the context of agriculture. Although there is some need for pediatric respiratory protective equipment, this review found that much of the guidance and available products are still adapted from adult FFR designs.

Regarding health and physiological impacts, this review found that most studies, even those involving moderate exercise, were cross-sectional in nature. Although most did not identify significant adverse health problems related to FFR use in youth, this conclusion was undermined by the fact that most of the studies utilized modified adult respirators due to a scarcity of youth-specific models for testing. This is reflected in the subjective discomforts of FFR use reported by youth, such as shortness of breath and facial pressure. Similar respirator fit-related discomfort issues are also common among adults (Harber 1984; Harber and Beckett 2024). However, these issues may be exacerbated in youth due to some additional challenges like the use of ill-fitting adult models, the limited availability of youth-specific FFR designs, and the lack of regulated fit-testing procedures for youth. Currently, both respirator certification methods and medical evaluations for respirator use in the US (e.g., 42 CFR, Part 84) are designed for adults, and it is

unknown if these procedures adequately assess the physiological demands on youth in agricultural settings. This suggests a significant research gap in applying adult-centric medical clearance or respirator fit-test protocols to the youth population.

The limited findings of this review on FFR fit and design demonstrate that a youth one-size-fits-all approach or the adaptation of adult-approved respirators may be inadequate for youth. The variability in youth facial anthropometrics, influenced by growth and dental development, necessitates respirator designs and sizing metrics based on individual facial measurements rather than age (Chvatal et al. 2005; Mellion et al. 2013). The Čuta et al. (2024) study, which virtually evaluated a 3D-printed mask, illustrated the importance of youth-specific design and distinct sizing categories due to lower FFR fit-test passing rates on individuals with smaller faces. This review highlights that while adult FFRs generally maintain their filtration efficiency at lower flow rates representative of youth breathing, optimal protection remains contingent on proper fit, which may be hindered by the lack of youth-specific designs and standardized fit testing. Although the fundamentals of respirator fit testing may be similar for adults and youth, there is a need to examine possible procedural changes for youth due to rapid physical development. Furthermore, current confidential procedures for medical evaluation and fit testing may include the involvement of parents or guardians. ISASH Working Group members also reported concerns about the appropriate fit-testing procedures for youth.

The synthesis of general guidance and compliance review literature emphasizes that, despite some environmental benefits of FFRs (e.g., wildfire smoke protection), the limited availability of youth-specific models remains a major barrier. FFR use and compliance is low in youth due to complaints about breathing resistance, facial pressure, heat buildup, and strap discomfort. Once appropriately designed and tested, youth FFR models can become readily available, then perhaps targeted education and training can proceed. In Table 4, the authors have summarized the potential risks and benefits of FFR use for youth in agriculture from the review. Key risks include poor fit, lack of proper testing and protocols, and potential health issues like elevated CO_2 levels, while benefits include protection against respiratory hazards and increased availability of youth-specific FFR models.

Limitations

This review was limited by the small number of overall meeting the stringent inclusion criteria was small ($n = 31$). It should be noted that a substantial number of potentially relevant studies had to be excluded due to their primary focus on undefined or non-respirator "masks" or "facial coverings" during the COVID-19 pandemic, often without focusing on specific youth populations or FFRs. The authors note that this review excluded studies that explored important considerations like the inhalation potential of volatile organic compounds (VOCs) and microplastics from general "mask" use but did not qualify for inclusion in this review given the focus on FFRs (Ma et al.

Table 4. FFR use among farm youth in the US, potential risks and benefits.

Risks	Benefits
Poor fit of adult-sized respirators on youth faces (even when modified), leading to reduced respiratory protection and increased discomfort (Goh et al. 2019; Lin and Chen 2017; Čuta et al. 2024; ISASH 2024)	Increasing availability of youth FFR models for purchase means that they will no longer need to use modified adult FFRs (Guha et al. 2015; Goh et al. 2019)
One-size-fits-all FFR design is likely inadequate for youth due to high facial dimension variability during developmental stages (Lei et al. 2014; Eberhart et al. 2021; Čuta et al. 2024; Khairul Hasni et al. 2023)	When fitted properly, FFRs offer protection against respiratory exposures related to farm or outdoor activities (e.g., wildfire smoke, air pollution, agricultural dusts, pathogens) (Holm et al. 2021; Li et al. 2021; ISASH 2024)
No protocols developed or required for proper medical evaluation and fit testing of youth for FFRs (ISASH 2024)	Medical evaluation and fit testing of youth is likely to be similar to that for adults (Lubrano et al. 2021; Happernegg and Kerbl 2023)
Youth are less likely to advocate for personal safety or report discomfort when wearing FFRs (ISASH 2024; Preest et al. 2024)	Initial problems with fit and discomfort is likely to subside with regular use and increased availability of youth FFR models (Preest et al. 2024)
Lack of testing on FFRs for youth risk of inhalation of VOCs, microplastics, other potentially hazardous compounds (Ma et al. 2021; Xie et al. 2021, 2022)	FFRs are constructed from nonwoven materials with potential for higher filtration efficiencies for youth due to lower face velocities (Seo et al. 2023)
Potential health risks related to elevated CO_2 levels and increased cardiopulmonary workload. resistance, facial pressure, heat buildup, and strap discomfort (de Yzaguirre i Maura et al. 2021; Walach et al. 2022)	Inhaled CO_2 levels may be lower with the use of valved FFR models (Lubrano et al. 2021; Goh et al. 2019)
Lack of youth-specific respiratory protection training curriculum (ISASH 2024)	Youth acceptance of FFR likely increases with educational intervention/outreach and adult modeling of behavior (Bhardwaj and Thompson 2022; Cuesta-Zigorraga et al. 2023; Slavik et al. 2023; ISASH 2024)

This table summarizes the potential risks and benefits of using filtering facepiece respirators (FFRs) for farm youth in the US based on the review. The information is organized by order of importance and matched by potential risk and benefit.

2021; Xie et al. 2021, 2022). Although most FFRs are made from FDA-regulated polypropylene, this doesn't exclude all potential models from containing other substances, highlighting another area for future research.

Some discrepancies were noted between the Rayyan AI tool's assessment and human reviewer screening, underscoring the current limitations of AI in fully replacing human judgment in systematic review processes (Blaizot et al. 2022). Most included studies focused on modified adult FFRs rather than respirators specifically designed for youth, which inherently limits the generalizability of findings regarding optimal youth-specific designs and performance.

Conclusion

This systematic review underscores an urgent need for comprehensive, evidence-based guidance on filtering facepiece respirator (FFR) use for youth working in agriculture in the US Current FFR designs, approval processes, and fit-testing protocols are predominantly adult-centric, leading to significant challenges in achieving adequate fit and ensuring optimal protection for youth. While FFRs appear physiologically tolerable for youth, subjective discomfort and the critical issue of proper fit due to diverse facial anthropometrics remain substantial barriers to both effective use and compliance. Future research must prioritize detailed youth facial anthropometric studies and potential use of headforms to inform the development of youth-specific FFR designs and standardized fit-testing protocols. Furthermore, guidance on pediatric medical evaluations before respirator use is critically needed. Ultimately, the authors believe that a concerted effort from manufacturers, researchers, and regulatory bodies is required to ensure that young agricultural workers have access to effective, comfortable, and properly fitting respiratory protective equipment.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Acknowledgments

The authors would like to acknowledge the International Society for Agricultural Health and Safety (ISASH) and their contribution by allowing the space and time for the Youth Respirators ISASH Working Group at the 2024 ISASH Conference (Portland, OR), and acknowledge the 11 external Working Group participants.

Funding

This work was funded by the National Children's Center for Rural and Agricultural Health and Safety (NCCRAHS) and the National Institute for Occupational Safety and Health (NIOSH) (U54 OH009568-10). NCCRAHS is a national organization dedicated to enhancing the health and safety of children and adolescents working in or living on farms.

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