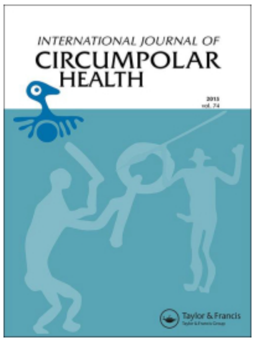

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Self-reported exposure to dust and diesel exhaust, respiratory symptoms, and use of respiratory protective equipment among Arctic miners

David Peyre-Costa [a], Albin Stjernbrandt [b], Jens Wahlström [b], Tiina Maria Ikäheimo [a,c] and Anje Christina Höper [a,d]

[a]Department of Community Medicine, Faculty of Health Sciences, UiT The Arctic University of Norway, Tromsø, Norway; [b]Section of Sustainable Health, Department of Public Health and Clinical Medicine, Umeå University, Umeå, Sweden; [c]Research Unit of Population Health, University of Oulu, Oulu, Finland; [d]Department of Occupational and Environmental Medicine, University Hospital of North Norway, Tromsø, Norway

ABSTRACT

Arctic miners face significant risks from diesel exhaust and dust exposure, potentially leading to adverse respiratory health. Employers must limit harmful exposures, using personal protective equipment (PPE) as a last line of defense. This study explored the association between reported respiratory exposure and symptoms, and PPE training and usage. Data from the MineHealth study (2012–2014) included a total of 453 Arctic open pit miners in Norway, Sweden, and Finland. Participants answered questions on exposure to dust and diesel exhaust, respiratory symptoms, and PPE use, in addition to age, gender, BMI, smoking, and self-rated health. Estimated exposure to dust was common, reported by 91%, 80%, and 82% and that of diesel exhaust by 84%, 43%, and 47% of workers in Sweden, Finland, and Norway, respectively. Reported dust exposure was significantly related to respiratory symptoms (OR 2.2, 95% CI 1.3–3.7), diesel exposure increased the occurrence of wheezing (OR 2.6, 95% CI 1.3–5.4). PPE use varied between the studied mines. Non-use was common and related to reduced visibility, wetness, skin irritation and fogging of the respiratory PPE. Future research should employ more precise exposure assessment, respiratory function as well as explore the reasons behind the non-compliance of PPE use.

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Arctic; open-pit mining; air pollutant; personal protective equipment; respiratory symptoms

Introduction

Located in the Arctic, the Barents region in the northernmost part of Norway, Sweden, Finland and North-West Russia, has many natural resources. This brings along workplaces that extract these resources and promote economic growth and development in the region. In the last decades new mines have been established in several locations, and old mines are expanded or reopened [1].

Miners in general are subjected to various occupational exposures such as air pollutants [2], chemicals, extreme temperatures, and ergonomic hazards due to heavy lifting or manual work [3]. Air pollution related to mining operations is mainly caused by exposure to dust from mining processes such as blasting and crushing of ore, as well as diesel exhaust originating from vehicle use [3,4].

Exposure to air pollutants can cause upper and lower respiratory symptoms and have adverse effects on respiratory function [5]. Cough, mucus production, wheezing in the chest, nasal congestion and runny nose are general respiratory symptoms that can be associated with air pollution and can also reflect the presence or aggravation of respiratory diseases [6,7]. Chronic dust and diesel exhaust exposure also increases the risk of respiratory diseases such as chronic obstructive lung disease (COPD) or lung cancer [8,9]. These negative health consequences will affect not only the individual workers' lives, but also result in increased costs for enterprises and society due to sick leave and other social security benefits [10,11].

Employers are required to provide a safe work environment and limit their workers' exposure to factors that are potentially harmful to their health. If general protective measures are insufficient, personal protective equipment (PPE) is to be provided [12,13]. PPE in mines usually include filtering respirators, safety goggles and helmets. Despite improvements in working conditions and increased use of PPE in the last decades, miners are still more likely to develop adverse respiratory health effects than the general population [14,15]. This underlines the importance of studying miners' exposure to dust and other airborne pollutants, in addition to the fact that Arctic mine operations may differ from other areas due

CONTACT David Peyre-Costa david.peyre-costa@uit.no Department of Community Medicine, Faculty of Health Sciences, UiT The Arctic university of Norway, Tromsø 9037, Norway

to extreme weather conditions, isolation, and the polar night in wintertime. These special conditions may require the use of heavy protective clothing in addition to PPE.

To our knowledge, there are no previous studies examining the association between air pollution and respiratory symptoms, nor the use of PPE by miners working in Arctic conditions. Previous research regarding data from the present study (MineHealth) have focused on musculoskeletal symptoms and exposure to whole-body vibration [16,17], low back pain [18,19], thermal perception thresholds [20], and thermal comfort sustained by cold protective clothing in Arctic open-pit mining [21]. The primary aim of this study was to assess self-reported exposure to air pollution of Arctic open pit mine workers and examine the association with respiratory symptoms. Our secondary aim was to examine the use of personal protective equipment.

Material and methods

Study design and general data collection

Three open-pit mines of the Arctic region (67 to 76°N) in Norway, Finland and Sweden, extracting various minerals (e.g. copper, gold, and nickel) were involved in the MineHealth study. This cross-sectional study collected data from 2012 to 2014. The participants were asked about their general health, diseases, and exposure to airborne pollutants through a questionnaire, translated into the native languages of the workers [22]. Additional information describing the characteristics of the study participants, such as age, sex, height, weight, body mass index (BMI, kg/m^2), smoking status, and education were also collected. BMI categories were classified as normal to underweight (BMI below 25 kg/m^2), overweight (25 kg/m^2 to below 30 kg/m^2) and obese (30 kg/m^2 or more). For assessing exposure to air pollution, the following questions were asked: "*are you exposed to diesel exhausts?*" and "*are you exposed to dust?*". The alternatives for answers included *"yes"* or "*no*" and estimating the number of hours exposed per week. Concerning work tasks, mine workers were classified as a "mining vehicle driver" when reporting to drive for at least five minutes on a daily basis. Any other workers were categorised as non-drivers.

Respiratory symptoms and use of personal protective equipment

For assessing the occurrence of respiratory symptoms at their work the participants answered the following questions: *"have you experienced wheezing in the chest at any time during the last twelve months?""; have you in the last few years been bothered by persistent (or chronic) cough?""; do you usually cough up mucus or do you have mucus in your chest that you have difficulty getting up?"* and *"have you ever had nasal symptoms such as nasal congestion, runny nose and/or sneezing without colds?"* with the answering options *"yes"* or "*no*". In the analyses, we created a new variable titled "respiratory symptom" that mandated reporting at least one of the studied respiratory symptoms. In addition to respiratory symptoms, the participants were inquired about having a doctor-diagnosed respiratory disease, such as asthma or COPD. The question on occupational exposure to dust was followed by the question: *"If yes, are you using PPE?"* with the reply to options "*never*", "*sometimes" "often*", and "*always*". Reasons for taking off their PPE and other modalities such as the training on how to use it were also inquired.

Statistical analysis

Univariate analyses were performed using Chi^2 test for nominal scale variables and Wilcoxon and Mann Whitney test for continuous scale variables. Crude and adjusted binary logistic regression were performed to evaluate the association between exposure to dust and diesel exhausts (independent variables) and respiratory symptoms (dependent variables). The binary logistic-regression analysis was used for analysing any associations (odds ratio, OR) between subjective reported symptoms and the exposure to dust or diesel. The analyses were adjusted for potential confounders, such as age, gender, BMI, smoking status, and asthma. The categorical variables were presented as numbers and valid percentages. The continuous scale variables were presented as means and standard deviations. All calculations were performed using SAS software v.9.4. The study was approved by the regional committees for medical research in each of the countries. All participants have given written informed consent.

Results

Descriptive characteristics

Of the total number of 674 employees 101 miners participated in Norway, 153 in Sweden and 199 in Finland, with a participation rate of 91.8%, 40.9% and 99.5%, respectively. The participants represented various occupations, where the main groups consisted of vehicle drivers, mechanics, and electricians.

The characteristics of the study participants, categorised by country are presented in Table 1. In summary, there was a greater percentage of female miners in

Table 1. Characteristics of the miners in Sweden, Finland, and Norway.

Characteristics	Total	Sweden	Finland	Norway	P value
Age, mean (SD)	449	39.9 (11.5)	35.7 (10.1)	41.8 (12.8)	<0.01
Males, n (%)	339	96 (62.8)	162 (81.4)	81 (81.8)	<0.01
Females, n (%)	112	57 (37.3)	37 (18.6)	18 (18.2)	
BMI	404				0.04
Normal – underweight, n (%)	144	46 (41.8)	72 (36.4)	26 (27.1)	
Overweight, n (%)	173	50 (45.5)	78 (39.4)	45 (46.9)	
Obese, n (%)	87	14 (12.7)	48 (24.2)	25 (26)	
Year of school completed, mean (SD)	440	11.8 (4.5)	8.9 (3.7)	11.8 (2.7)	<0.01
Daily smoking	121	21 (13.9)	67 (33.7)	33 (34.4)	<0.01
Exposure to diesel exhaust	209	124 (84.4)	85 (43.2)	46 (46.5)	<0.01
Exposure to dust	294	136 (91.3)	158 (79.8)	75 (82.4)	<0.01
If exposed to dust, are you using local exhaust equipment?					<0.01
Never/sometimes	256	124 (91.9)	60 (49.6)	72 (81.8)	
Often/always	88	11 (8.2)	61 (50.4)	16 (18.2)	
If exposed to dust, are you using PPE?					<0.01
Never/sometimes	195	69 (51.5)	54 (39.1)	72 (80.9)	
Often/always	166	65 (48.5)	84 (60.9)	17 (19.1)	
Airway symptoms					
Persistent or chronic cough	447	25 (16.3)	27 (13.9)	11 (11.1)	NS
Mucus	447	32 (20.9)	42 (21.5)	28 (28.3)	NS
Nasal symptoms	445	76 (50.3)	118 (60.5)	58 (58.6)	NS
Wheezing in the chest	446	30 (19.6)	39 (20.1)	28 (28.3)	
Respiratory symptoms (at least one of the above)	449	93 (60.8)	125 (63.5)	68 (68.7)	NS
COPD		NA	1 (0.5)	0 (0.0)	NS
Asthma		NA	19 (9.7)	12 (12.1)	NS

Sweden compared to the other location, and Norwegian miners tended to be more overweight or obese compared to Finnish and Swedish miners. Smoking was less common among Finnish miners compared to the Norwegian and Swedish ones. Among the 47% of participants who reported diesel exposure and the 65% who reported dust exposure, Swedish workers reported being most exposed, followed by Norwegian and Finnish miners.

Personal protective equipment

Table 2 highlights PPE use in the studied mines. Finland has a higher proportion of miners declaring using PPE often/always, both for wearing a half and full mask when exposed to dust. At the same time, Finnish miners also reported more often problems especially related to the use of full respiratory masks (18% for Finland versus 3% and 4% respectively for Sweden and Norway). Furthermore, Finish miners reported a notable lower level of training to use or to maintain their PPE, in addition to having a lesser number of clean places to store them. Non-use of PPE was more common in Sweden compared with the other countries. Finally, the Swedish mine had a higher number of drivers ($n = 139$, 91%) compared to Finland ($n = 101$, 51%) or Norway ($n = 53$, 53%) of the employees working in the mines.

The reasons for non-use of PPE were various and the proportions quite similar in all the mines. Indeed 27% of the miners in all mines declared removing PPE often or always due to visibility limitation, 32% because PPE are wet or foggy, and 18% because of skin irritations.

Associations between reported exposure to air pollution and respiratory symptoms

Miners in the study frequently reported respiratory symptoms, including nasal symptoms, mucus production, chest wheezing, and chronic cough. Reported occupational exposure to dust (Table 3) was significantly related with all inquired respiratory symptoms, both according to crude and adjusted models.

We detected that reported exposure to diesel exhaust was associated with a higher reporting of wheezing (Table 4). The association was stronger when adjusting for reported diagnosed asthma (31 participants).

Discussion

Main findings

To our knowledge, this study is the first to report data on miners' dust and diesel exposure, respiratory symptoms, and the use of PPE in the Arctic region. Our results showed that miners of open pit mines commonly reported exposure to air pollution, especially dust. We further detected that reported occupational exposure to dust was associated with a higher occurrence of respiratory symptoms. Reported exposure to diesel exhaust was not as strongly related to respiratory symptoms. Despite the high prevalence of the reported respiratory symptoms and exposure to air pollution, the use of PPE varied between different mines in the Nordic countries.

Table 2. Characteristics of the use of personal protective equipment and training according to the country.

Variable	Total		Total n (%)	Sweden n (%)	Finland n (%)	Norway n (%)
Use of half mask	378	Never/sometimes	338 (89.4)	129 (97)	135 (79.4)	74 (98.7)
		Often/always	40 (10.6)	4 (3)	35 (20.6)	1 (1.3)
Use of full mask	371	Never/sometimes	344 (92.7)	127 (95.5)	143 (87.7)	74 (98.7)
		Often/always	27 (7.3)	6 (4.5)	20 (12.3)	1 (1.3)
Experience of problems with compatibility between different protective equipment	425	Never/sometimes	383 (90.1)	144 (97.3)	152 (81.7)	87 (95.6)
		Often	42 (9.9)	4 (2.7)	34 (18.3)	4 (4.4)
Taking off personal protective equipment (PPE) while working	421	Never/sometimes	361 (85.8)	114 (77)	162 (88)	85 (95.5)
		Often	60 (14.3)	34 (23)	22 (12)	4 (4.5)
Reasons for taking off PPE:						
To discuss with the others	271	Never/sometimes	195 (72)	75 (72.8)	73 (62.9)	47 (90.4)
		Often/always	76 (28)	28 (27.2)	43 (37.1)	5 (9.6)
To listen to what happens around	229	Never/sometimes	192 (83.8)	72 (85.7)	77 (80.2)	43 (87.8)
		Often/always	37 (16.2)	12 (14.3)	19 (19.8)	6 (12.2)
Due to pressure or skin irritation	238	Never/sometimes	194 (81.5)	73 (83.9)	76 (77.6)	45 (84.9)
		Often/always	44 (18.5)	14 (16.1)	22 (22.5)	8 (15.1)
Since PPE limits visibility	262	Never/sometimes	191 (72.9)	76 (91.6)	77 (65.3)	38 (62.3)
		Often/always	71 (27.1)	7 (8.4)	41 (34.8)	23 (37.7)
Since PPE are wet or foggy	275	Never/sometimes	188 (68.4)	78 (95.1)	62 (51.7)	48 (65.8)
		Often/always	87 (31.6)	4 (4.9)	58 (48.3)	25 (34.3)
Having a clean place to store PPE?	419	No	91 (21.7)	16 (11)	66 (36.5)	9 (9.8)
		Yes	328 (78.3)	130 (89)	115 (63.5)	83 (90.2)
Having been trained to use PPE?	422	No	99 (23.5)	25 (16.9)	66 (36.3)	8 (8.7)
		Yes	323 (76.5)	123 (83.1)	116 (63.7)	84 (91.3)
Having been trained to maintain PPE?	421	No	203 (48.2)	63 (42.6)	107 (58.8)	33 (36.3)
		Yes	218 (51.8)	85 (57.4)	75 (41.2)	58 (63.7)

Table 3. Association between reported exposure to dust and the respiratory symptoms. The estimates are presented as odds ratios (OR) and their 95% confidence intervals.

Occurrence of symptoms	Unadjusted	Model 1*	Model 2**
Any respiratory symptom	2.2 (1.3–3.7)	2.7 (1.5–5)	3.1 (1.5–6.2)
Wheezing	3.9 (1.5–9.9)	3.7 (1.4–9.9)	4.1 (1.1–14.9)
Cough	6.2 (1.5–26.0)	13.4 (1.8–102.3)	8.6 (1.1–69.3)
Mucus	2.9 (1.3–6.5)	3.4 (1.4–8.5)	3.1 (1.1–8.3)
Nasal Symptoms	1.9 (1.1–3.2)	2.1 (1.2–3.8)	2.7 (1.4–5.4)

*Adjusted for age, gender, BMI, and daily smoking.
**Adjusted for age, gender, BMI, daily smoking, and asthma.

Reported exposure to air pollution and its association with respiratory symptoms

A substantial number of workers reported exposure to air pollution in Arctic mines. Indeed, exposure to dust was reported by up to 91% and exposure to diesel exhaust by up to 84% of the miners, depending on the country. Estimated diesel exposure was much higher and dust exposure slightly higher in Sweden compared to the mines in Norway and Finland. The reason for these reported differences could relate to differences in the overall operations between the Arctic mines, as well as different occupational groups that the participants belonged to. For instance, a large proportion of the Swedish participants were drivers of diesel-electric haul trucks and therefore likely commonly exposed to diesel exhaust. The differences could also be due to recall bias, where the most exposed workers could have been more prone to recall and participate in the study.

When comparing the prevalence of symptoms by country, our study did not detect differences between the studied mines despite the reported differences in estimated exposure to dust, diesel exhaust, and use of PPE. In the multivariable analysis, worker-estimated

Table 4. The association between reported exposure to diesel exhaust of miners on their respiratory symptoms. The estimates are presented as odds ratios (OR) and their 95% confidence intervals.

Occurrence of symptoms	Unadjusted	Model 1*	Model 2**
Any respiratory symptom	1.2 (0.8–1.7)	1.3 (0.9–2.0)	1.3 (0.7–2.1)
Wheezing	1.7 (1–3.0)	**1.8 (1.0–3.6)**	**2.6 (1.3–5.4)**
Cough	1.7 (0.9–3.0)	1.9 (0.9–3.5)	1.9 (0.9–4.1)
Mucus	1.2 (0.8–1.9)	1.3 (0.8–2.0)	1.2 (0.7–2.4)
Nasal Symptoms	1 (0.7–1.5)	1.1 (0.7–1.7)	1.1 (0.6–1.8)

*Adjusted for age, gender, BMI, and daily smoking.
**Adjusted for age, gender, BMI, daily smoking, and asthma.

exposure to dust was related to frequent reporting of respiratory symptoms, 61% to 69% declared having at least one of the studied symptoms. About 50% to 60% of the participants reported having nasal symptoms such as nasal congestion, runny nose, or sneezing without colds. The observed association between estimated dust exposure and reporting of respiratory symptoms may indicate irritation of the respiratory tract of the miners. Even if the air pollution was not measured, mining operations are known to generate air pollutants such as dust when the ore is crushed, and diesel exhausts due to the use of fossil fuel engines [23–25]. In addition, there can be other relevant air pollutants such as welding fumes or chemicals (solvents, oils, cutting fluids). The latter was only inquired in one of the countries, and not for all the listed factors. It is important to mention that participation rate was various between the mines. The lower willingness to participate from the mine in Sweden could relate, for example, to whether the workers were employed through a staffing company or not. Especially temporary workers may more often decline to participate to this type of study. Unfortunately, we do not have this information.

Findings were not as clear for the associations between estimated diesel exhaust and reported respiratory symptoms. This is somewhat contradictory to previous findings showing adverse effects on respiratory health, inducing several respiratory symptoms [26,27]. The reason for the lack of associations in our study could be because the intensity of exposure to diesel exhaust was not sufficient to elicit respiratory symptoms. Though, the current study does not allow elaborating the amount of exposure to diesel exhaust. Alternatively, the limited population size could also have affected the ability to detect an association between the exposure and respiratory symptoms.

Our results showed an association between estimated dust exposure and several respiratory symptoms, which is in line with what can be found in the literature in other surface mines [28]. However, since cumulative exposure to dust is known to be a significant risk factor for the development of respiratory diseases such as COPD, which can manifest with the symptoms we studied [29], more objective measurement such as pulmonary function data (i.e. spirometry) could have helped confirming our findings. Indeed, respiratory symptoms can be a poor indicator of actual respiratory impairment assessed by spirometry, especially in middle and older-aged patients [30,31], and further studies are required to determine if these work environments cause a decline in lung function.

Is it also important to consider that working outdoors in the Arctic region implies regular exposure to cold ambient temperature. Occupational cold exposure has been found to be associated with incident wheeze and productive cough in previously healthy individuals [32,33].

Simultaneous exposure to cold and air pollutants could possibly potentiate respiratory symptoms. However, the current study was not designed to distinguish between these exposures.

Use of PPE

In our study, the use of PPE differed greatly between the studied mines. Our results indicated that 50% to 80% of the miners declared to never or only sometimes use PPE when exposed to dust. It is difficult to assess the reasons for the differences in use, as the regulations should be relatively similar in the Nordic countries, and in the European Union in general. Indeed, if general ventilation measures are insufficient to protect workers from air pollution, efficient and wearable PPE must be provided by the employer in the European Union [13]. However, our findings showed that a substantial proportion of miners declared removing their PPE often or always because of discomfort or problems such as skin irritation, PPE getting wet or foggy or because it limits visibility. Miners also tended to remove their PPE to discuss with others or to listen to what happens around, which represents a potential safety risk. The use of personal protective equipment, like respirators, should limit neither communication nor the ability to hear sounds of the surroundings. Our findings are in line with previous studies explaining that the non-use of PPE could relate to their effectiveness, comfort, to various social influences or safety climate of workplaces [34]. This non-use can be partially reduced by proper training on how to use and maintain PPE, but not completely due to physiological and psychological reasons [35].

Also, differences in the mining processes or miners' work tasks could explain the differences in PPE use. Indeed, drivers tended to use their PPE less than non-drivers. Therefore, the high number of drivers in the Swedish mine (91%) compared to Finland (51%) and Norway (52%) could partially explain the differences in the use of PPE. We unfortunately have no data to further confirm these assumptions. We hypothesised that the use of PPE would reduce exposure to air pollution and involve less respiratory symptoms. Unfortunately, missing data on the use of PPE, and a high covariance between the PPE use and the estimated exposure to dust, combined with a small number of estimated unexposed subjects did not allow us to model the use of PPE.

Applicability of the results

This study shows that Arctic open pit miners frequently report respiratory symptoms which appears to be related to their self-reported exposure to air pollution. The finding is important to be considered both by employers and employees involved in the mining industry to further improve the working conditions. Employers could use the information for developing their occupational health and safety management systems. Individual employees should be better aware of the potential hazards of air pollution on health and how to protect themselves by for example using PPE. The obtained information may apply to other open-pit mines in the Arctic countries.

Strengths and limitations of the study

To our knowledge, this is the first study to evaluate exposure to air pollution, respiratory symptoms, and the use of PPE of open pit mines operating in the Arctic region. The data was rigorously collected in a similar way between the countries and with a high participation rate in Finland and Norway.

The data involves some limitations, as well. The cross-sectional design did not allow to reach temporal causation between exposure (air pollution) and outcome (respiratory symptoms). In addition, the collected data on exposure and outcome was self-reported, which can lead to recall bias, as well as under- or overestimation of exposure and outcomes. Measurements of lung function could have supplied additional objective data on respiratory impact but were not performed in the study. Furthermore, the wording of the symptoms' questions such as "have you ever had nasal symptoms (…)?" or "have you in the last few years been bothered by persistent (or chronic) cough" could lead to interpretation problems in terms of temporality, and accuracy of the potential relation with the exposure to air pollutants. In addition, bias may have affected our results due to awareness related to the effects of industrial pollutants on health [36]. The relatively small sample size affected the possibility for multiple adjustments in logistic regression analyses. Finally, we cannot exclude residual confounding of unmeasured variables.

Conclusions

Our study showed considerable reported exposure to air pollution among Arctic miners, where especially estimated exposure to dust was related to a high prevalence of respiratory symptoms. Further studies are needed that include more detailed and objective measures of air pollution among miners, as well as detailed clinical assessments of respiratory function. In addition, the reasons for the non-use of PPE warrant further research.

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Disclosure statement

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

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Data availability statement

The dataset used during the current study can be made available upon reasonable request to the corresponding author.

ORCID

David Peyre-Costa http://orcid.org/0000-0002-4949-0691
Albin Stjernbrandt http://orcid.org/0000-0001-6082-8465
Jens Wahlström http://orcid.org/0000-0002-2359-509X
Tiina Maria Ikäheimo http://orcid.org/0000-0002-2763-6004
Anje Christina Höper http://orcid.org/0000-0002-8962-5853

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