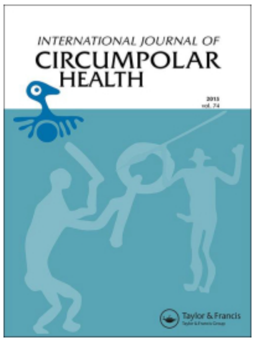

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Neurosensory and vascular symptoms and clinical findings in the hands of Arctic open-pit miners in Sweden and Norway – a descriptive study

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ABSTRACT

This cross-sectional study aimed to describe exposure to cold climate and hand-arm vibration (HAV) as well as neurosensory and vascular symptoms and clinical findings among open-pit Arctic miners. It was based on data from questionnaires and physical examinations, including 177 men and 75 women from two open-pit mines in Sweden and Norway (response rate 54%). Working outdoors or in an unheated building or machine for at least two hours per day was reported by 44% and HAV exposure of the same duration by 10%. Neurosensory symptoms (e.g. reduced perception of touch) in the hands were reported by 47% and Raynaud's phenomenon by 14%. In brief conclusion, the study showed that Arctic miners were commonly exposed to both cold temperatures and HAV. They also reported a broad range of neurosensory and vascular symptoms in their hands and had abnormal clinical findings related to the symptoms. The results emphasise the need for additional preventive measures in this occupational setting.

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Cold climate; vibration; mining; Sweden; Norway; peripheral nervous system diseases; Raynaud disease

Introduction

The Arctic region offers specific challenges with long and cold winters, where outdoor workers are subjected to harsh climate [1]. One specific work environment that is present in the Nordic countries is mining of different sorts. Open-pit mining is the most common practice worldwide and differs from underground mining from an occupational health and safety perspective, since the workers are more exposed to the open-air ambient environment rather than being protected from the surrounding climate as in underground mining. Open-pit mining also involves different work tasks compared to underground mining [2]. Specific open-pit mining tasks include building the mine infrastructure with benches, batters, dewatering bores, and access roads [3]. When in operation, workers usually conduct ground sampling, drilling, blasting, excavating, loading, and transporting of ore. The production requires frequent maintenance of heavy machinery such as loaders, haul trucks, conveyor belts and ore crushers. Occupational exposures in this setting include ambient and contact cooling in combination with wind and precipitation, hand-arm vibration (HAV), whole-body vibration, inorganic dust, exhaust gases, and noise [1,4,5].

Previous studies on the Scandinavian working population have shown that neurosensory and vascular symptoms affecting the hands are quite common [6,7]. Furthermore, such symptoms have been related to exposure to both cold climate and HAV [8,9]. Therefore, it is likely that open-pit miners in this region would report a high occurrence of such symptoms, but this has not previously been studied in detail. Thus, the rationale of our paper was to describe both self-reported physical working conditions as well as symptoms and clinical findings in the hands of Arctic open-pit miners to highlight a potentially hazardous working environment that has not been sufficiently recognised. In general, neurosensory hand symptoms indicate dysfunction in the afferent sensory peripheral nerves that relay sensory information from cutaneous receptors to the central processing in the thalamus and cerebral cortex [10]. Neurosensory symptoms can be divided into positive symptoms (gain-of-function, e.g. paraesthesiae, tingling, burning, or allodynia) and negative symptoms (loss-of-function, e.g. reduced perception of touch, cold, warmth, vibration, or pressure) [10]. Such symptoms are often reported to be long-standing [10]

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and can have effects on both quality of life and work ability [11–13]. The symptoms are often considered to indicate peripheral nerve injury, for which there are no effective medical or surgical treatments, and this emphasises the need for early preventive action. A separate but related neuropathic condition is carpal tunnel syndrome, which mainly causes nocturnal symptoms in the thumb, index, and middle finger, and can be related to both HAV, repetitive wrist flexion, forceful handgrip use, and cold exposure [14,15]. In the clinical setting, testing of neurosensory function is often focused on either large or small afferent sensory fibres. The function of large fibres (i.e. of Aα and Aβ subtype) can be assessed by testing exerted muscle force and tendon reflexes as well as proprioception and perception of touch and vibration. Small fibres (i.e. of Aδ and C subtype) constitute a larger part of the afferent sensory nerves but are more challenging to assess. In the clinical setting, small fibre function is mainly evaluated based on responses to pain and temperature stimuli [10]. Vascular hand symptoms include low finger skin temperature, cutaneous colour changes (e.g. acrocyanosis, erythema, or livedo reticularis) and Raynaud's phenomenon (RP). The latter has been the focus of much research, and for vibration-induced RP the prognosis has been described to be somewhat better as compared to neurosensory injury, where roughly half of symptomatic subjects can improve if exposure to HAV is ceased [16]. Finally, abnormal cold sensitivity is an ambiguous symptom that can be related both to neural and vascular dysfunction [17,18].

The aim of this study was to describe self-reported exposure to cold climate and hand-arm vibration as well as neurosensory and vascular symptoms and clinical findings in the hands of Arctic open-pit miners working in one Swedish and one Norwegian site.

Materials and methods

Study design and setting

This study was conducted between November 2012 and November 2013 in two open-pit mines in Sweden and Norway, as a part of the MineHealth project that aimed to improve the well-being, health, and work ability of miners in the Barents region, and has previously been described in detail [5,19]. Both mines were situated above the Arctic Circle, and according to the Swedish Meteorological and Hydrological Institute, the average monthly ambient temperature in the winter (January) was about – 14°C in the area of the Swedish mine and about – 9°C in the Norwegian mine. The Swedish mine was operational all year round while the Norwegian mine closed the open-pit operations during the harshest winter periods. The study included men and women of different occupations, but all worked outdoors to some extent. When invited to participate, the workers were given both oral and written information about the study and subsequently gave written consent to participate. The study protocol was approved by the Regional Ethical Review Board for medical research in Umeå, Sweden (DNR 2012–365-31 M), as well as in Oslo, Norway (DNR 2013/1026/REK).

Description of materials

The study protocol, including two written-response surveys, was developed by the MineHealth consortium and was based on the Nordic Musculoskeletal Questionnaire [20], the VIBRISKS survey [21], and the Workers' Health 2010 questionnaire [22]. The two surveys were first constructed in English and subsequently translated to Swedish and Norwegian before administration. At inclusion, the study participants were asked to complete the first nine-page general survey with questions regarding anthropometry, tobacco habits, socio-economic factors, occupational title, exposures at work, and general health. They were then offered to take part in an on-site clinical examination performed by consultant physicians specialised in occupational and environmental medicine. At this instance, they were asked to complete a second nine-page survey with more detailed questions on previous diseases, family history of diseases as well as occurrence of neurosensory and vascular symptoms. The questionnaire item regarding RP was supported by a standardised colour chart to increase the diagnostic accuracy [23,24]. Most questions were answered *yes* or *no*, but for some items there were four response alternatives (*none*; *insignificant*; *somewhat*; or *a lot*). In further analyses of items with four response alternatives, data were dichotomised so that answering *none* or *insignificant* was considered a negative response and answering *somewhat* or *a lot* a positive response.

Neurosensory testing was conducted on the volar aspect of the fingertips of the index and little fingers of both hands. Perception of touch was assessed using a five-piece Semmes – Weinstein monofilament hand kit (Touch-Test®, North Coast Medical, Gilroy, USA) and inability to perceive 0.4 grams of target force in at least one out of three attempts was considered an abnormal result. Perception of vibration was evaluated using a tuning fork of 128 Hz. Perception of temperature was assessed using 25 and 40°C temperature rollers (Rolltemp, Somedic SenseLab AB, Södsala, Sweden), where inability to discriminate one from the other was considered abnormal. Sharp pain was tested using an upholstery needle with one sharp and one blunt end, where inability to discriminate between the two was considered abnormal. Allodynia was assessed using a standardised pressure application tool (Algometer, Somedic SenseLab AB, Sösdala, Sweden). The clinical examinations were performed in an indoor environment with an ambient temperature of 20–22°C. Finger skin temperature was measured using an infrared thermometer (Testo 845, Alton Hampshire, UK) and the hands were warmed if < 28°C before examination.

Statistical analysis

Numerical data were described as median values with interquartile range (IQR), while categorical variables were presented as numbers and valid row percentages, unless otherwise specified. Missing data were omitted from analyses. The results were stratified based on mining site since both the mining procedure and the composition of the work force were expected to differ. Monotonic correlation between scales was investigated using Spearman's rank correlation coefficient (r_s). Statistical associations between categorical variables were investigated using Pearson's chi-squared test. A p value < 0.05 was considered statistically significant. Statistical analyses were performed using IBM SPSS Statistics for Windows (Version 28, IBM Corporation, Armonk, NY, USA).

Results

Participants and descriptive data

Out of a total 485 workers listed on the employee rosters, 260 agreed to participate, yielding a response rate of 53.6%. There were no data available on non-responders. Missing data in the questionnaire ranged from 3.5 to 9.6% depending on the item. The study sample consisted of 177 (70.2%) men and 75 women, with a median (IQR) age of 44 (20) and 35 (18) years, respectively. The participants were employed in a broad range of occupations, including samplers, drillers, drivers of heavy equipment, crusher operators, mechanics, electricians, water technicians, and foremen. There was a larger proportion of female workers in the Swedish mine, and most of them operated haul trucks or loaders. Additional descriptive data are presented in Table 1.

Exposure to cold and hand-arm vibration

Working outdoors or in an unheated building or machine was reported by 153 subjects (71.8%). Of these, 92 (71.9%) were working in the Swedish and 61 (71.8%) in the Norwegian mine, indicating no significant difference in exposed proportion of workers between countries ($p = 0.986$). The median daily exposure time was 2.0 hours (IQR 5.0; interval 0.1–11.0) and 3.0 hours (IQR 3.0; interval 0.5–15.0), respectively. Being exposed to these conditions for two hours per day or more was reported by 92 subjects (44.2%) in total. Stratified by country, there were 49 subjects (39.2%) in the Swedish and 43 subjects (51.8%) in the Norwegian mine that reported exposure for two hours per day or more ($p = 0.073$). Regarding wind, 104 subjects (40.0%) stated that it sometimes caused problems for them, while 42 subjects (16.2%) reported that it often caused problems. The work garments sometimes got wet for 120 subjects (46.2%) and often for 20 subjects (7.7%). In mild cooling conditions (−5 to + 5°C), 37 subjects (24.6%) reported perceived finger coldness and 20 subjects (13.3%) whole-body coldness. For severe cooling conditions (−20 to − 10°C), the figures were 73 (53.7%) and 45 (34.8%), respectively.

Table 1. Descriptive characteristics of the study participants, categorised by country.

		Sweden		Norway	
Variable	Categories	N	%	N	%
Participants	–	153	–	107	–
Age	18–29	36	23.5	25	25.3
	30–41	47	30.7	17	17.2
	42–53	48	31.4	37	37.4
	54–64	22	14.4	20	20.2
Gender	Male	96	62.7	81	81.8
	Female	57	37.3	18	18.2
Body mass index (BMI; kg/m^2)	BMI <25	46	41.8	25	26.3
	25≤BMI <30	50	45.5	45	47.4
	BMI ≥30	14	12.7	25	26.3
Smoking	Yes	21	13.9	33	34.4
	No	130	86.1	63	65.6
Educational level	Elementary (≤9 years)	15	9.9	13	13.3
	High school (10–12 years)	104	68.9	48	49.0
	Advanced (>12 years)	32	21.2	37	37.8

Valid column percentages are presented.

Working with handheld vibrating tools was reported by 72 subjects (29.2%). Of these, 41 subjects (26.8%) were working in the Swedish and 31 subjects (34.1%) in the Norwegian mine, indicating no significant difference in exposed proportion of workers between countries ($p = 0.229$). The median daily exposure time was 0.6 hours (IQR 1.2; interval 0.1–12.8) and 1.0 hours (IQR 1.0; interval 0.5–7.0), respectively. Being exposed to HAV for two hours per day or more was reported by 24 subjects (9.7%) in total. Stratified by country, there were nine subjects (5.9%) in the Swedish and 15 subjects (16.5%) in the Norwegian mine that reported exposure for two hours per day or more ($p = 0.007$). There was a positive correlation between hours working outdoors or in an unheated building or machine and hours working with handheld vibrating tools ($r_s = 0.39$; $p < 0.001$)

Neurosensory and vascular symptoms

Based on the surveys, having ever sustained a local cold injury was reported by 92 subjects (38.0%), and several had contracted multiple local cold injuries. Regarding the severity of local cold injuries, 84 reported dermal paleness with loss of sensation, 20 clear blistering, and five blood-filled blisters or blackish eschars. Any occurrence of neurosensory symptoms in the hands, affecting one or several sensory modalities, was reported by 109 subjects (46.6%), of which 36 were currently working with handheld vibrating tools. Out of the eight different neurosensory symptoms investigated in our study, most subjects reported one or two of these (Figure 1). There was no statistically significant difference in frequency of neurosensory symptoms between countries ($p = 0.133$). Nocturnal pain or numbness in the hands, suggestive of carpal tunnel syndrome, was reported by 57 subjects (23.3%). Detailed information on neurosensory symptoms, stratified by country, is presented in Table 2.

Regarding vascular symptoms, experiencing abnormally cold hands was reported by 60 subjects (25.1%), and having RP (as established using the standardised colour chart) by 36 subjects (13.9%), of which 18 reported currently working with handheld vibrating tools. The 18 subjects with RP constituted 25% of the HAV-exposed workers. Furthermore, RP was more commonly reported in Sweden than Norway ($p = 0.005$). Detailed information on vascular symptoms, stratified by country, is presented in Table 3.

Neurosensory and vascular clinical findings

There was a range of abnormal clinical findings, which are presented in Table 4, stratified by country and hand. Regarding large fibre dysfunction, there were four subjects (4.1%) that had reduced sensory perception of touch (i.e. inability to discriminate target force of 0.4 grams), all working in the Norwegian mine. In the same location, 34 subjects (34.3%) were unable to discriminate cold from warmth (25 and 40°C temperature rollers), as a measure of small fibre dysfunction. There were 21 subjects (18.4%) with a positive Tinel's test, and 17 subjects (15.5%) with a positive Phalen's test. Among those who reported nocturnal pain or numbness in

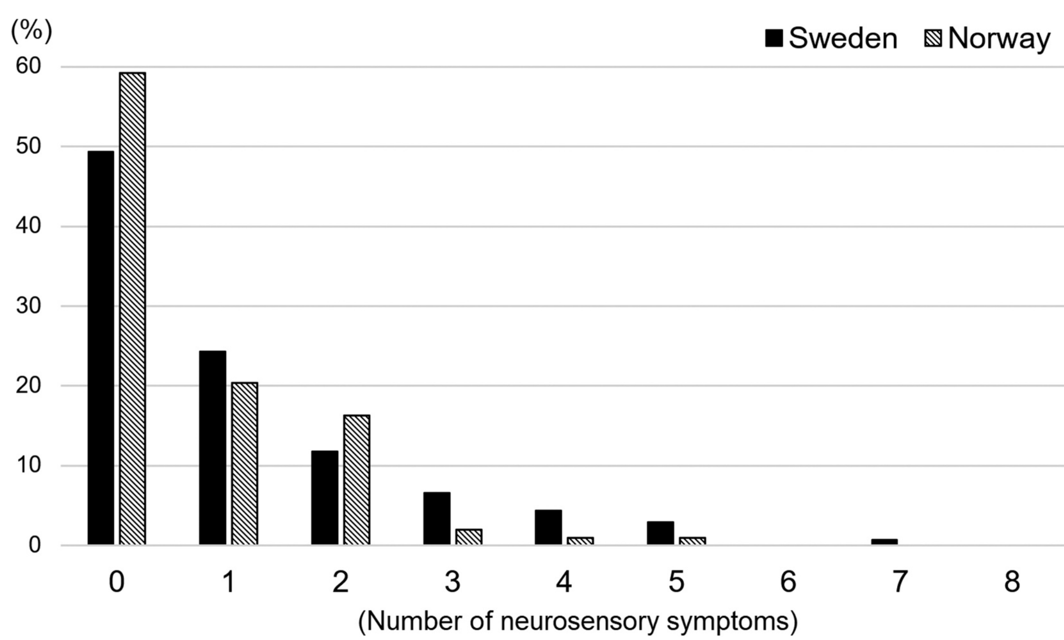

Figure 1. The proportion of simultaneously reported neurosensory symptoms in the hands, categorised by country.

Table 2. Neurosensory hand symptoms, categorised by country.

		Sweden		Norway	
Variable	Categories	N	%	N	%
Reduced perception of touch	No	137	90.1	95	96.0
	Yes	15	9.9	4	4.0
Reduced perception of cold	No	145	96	99	100.0
	Yes	6	4.0	0	0.0
Reduced perception of warmth	No	137	90.1	98	99.0
	Yes	15	9.9	1	1.0
Reduced hand grip strength	No	122	80.8	89	89.9
	Yes	29	19.2	10	10.1
Nocturnal pain or numbness	No	116	79.5	72	72.7
	Yes	30	20.5	27	27.3
Increased sweating	No	123	80.9	87	87.9
	Yes	29	19.1	12	12.1
Tendency to drop objects	No	129	89.0	92	92.9
	Yes	16	11.0	7	7.1
Difficulty fastening buttons	No	133	92.4	94	93.0
	Yes	11	7.6	7	7.0
One or more of the above	No	67	49.3	58	59.2
	Yes	69	50.7	40	40.8

Valid column percentages are presented.

Table 3. Vascular hand symptoms, categorised by country.

		Sweden		Norway	
Variable	Categories	N	%	N	%
Abnormally cold hands	No	98	70.0	81	81.8
	Yes	42	30.0	18	18.2
Difficulty withstanding cold (abnormal cold sensitivity)	No	104	77.0	80	80.8
	Yes	31	23.0	19	19.2
Swelling of fingers	No	117	77.0	92	92.9
	Yes	35	23.0	7	7.1
Abnormal colour change of fingers	No	116	85.3	91	91.9
	Yes	20	14.7	8	8.1
Abnormal colour of fingers	Blue	1	5.0	0	0.0
	White	16	80.0	7	77.7
	Red	1	5.0	1	11.1
	At least two of the above	2	10.0	1	11.1
Demarcated white fingertips	No	86	87.8	92	92.9
	Yes	12	12.2	7	7.1
Raynaud's phenomenon (as indicated on colour chart)	No	115	79.9	91	92.9
	Yes	29	20.1	7	7.1

Valid column percentages are presented.

their hands, a positive Tinel's test was found in ten subjects, and a positive Phalen's test also in ten subjects. An abnormal finger skin temperature was found in 154 subjects (62.6%). Regarding possible neurosensory HAV injury, there were ten subjects that reported occupational exposure to HAV, at least one neurosensory symptom of those listed in Table 2, and at least one clinical finding indicating reduced sensory perception (i.e. abnormal findings regarding touch, vibration, temperature, or sharp pain). These ten subjects constituted 13.9% of the HAV-exposed workers.

Discussion

Interpretation

Our study showed that roughly 44% of Arctic open-pit miners reported working outdoors or in an unheated building or machine for at least two hours per day, and about 10% worked with handheld vibrating tools to the same extent. This can be compared to official Swedish statistics, where 17% of the workforce is exposed to cold and 8% to vibration from handheld machines for at least one quarter of their working time (i.e. two hours of a normal eight-hour day) [25]. In turn, official Norwegian statistics report that 14% work in cold surroundings and 5% are exposed to HAV for at least a quarter of their work day [26]. This implies that the Arctic open-pit miners in our study were typically exposed over a longer time to these physical work environment factors than the average among workers in Sweden and Norway. In addition, the subjects were also exposed to other factors that aggravated the effect of ambient cooling, such as wind and moisture, where roughly 56% reported that wind caused problems and 54% that their work garments got wet. The pronounced

Table 4. Neurosensory and vascular clinical and laboratory findings, categorised by country and hand.

		Sweden				Norway			
		Right hand		Left hand		Right hand		Left hand	
Variable	Categories	N	%	N	%	N	%	N	%
Touch (monofilament)	0.07 g	76	56.3	81	60.4	42	43.3	43	44.3
	0.4 g	59	43.7	53	39.6	51	52.6	50	51.5
	2 g	0	0.0	0	0.0	4	4.1	4	4.1
Vibration (tuning fork 128 Hz)	Normal	135	88.8	135	88.8	99	100.0	99	100.0
	Abnormal	17	11.2	17	11.2	0	0.0	0	0.0
Temperature (rolls 40/25°C)[a]	Normal	–	–	–	–	68	68.7	65	65.7
	Abnormal	–	–	–	–	31	31.3	34	34.3
Sharp pain (upholstery needle)	Normal	128	84.2	130	85.5	97	98.0	96	97.0
	Abnormal	24	15.8	22	14.5	2	2.0	3	3.0
Allodynia	Not present	122	80.3	122	80.3	99	100.0	98	100.0
	Present	30	19.7	30	19.7	0	0.0	0	0.0
Skin appearance	Normal	115	77.7	115	77.7	93	94.9	93	94.9
	Erythematous	11	7.4	11	7.4	3	2.1	3	2.1
	Livedo pattern	22	14.9	22	14.9	2	2.0	2	2.0
Skin perspiration	Dry	92	62.2	92	62.2	85	87.6	85	87.6
	Clammy	56	37.8	56	37.8	12	12.4	12	12.4
Tinel's test	Negative	141	92.2	138	90.2	94	94.9	93	93.9
	Positive	12	7.8	15	9.8	5	5.1	6	6.1
Phalen's test	Negative	143	93.5	142	92.8	92	93.9	93	93.9
	Positive	10	6.5	11	7.2	6	6.1	6	6.1
Allen's test for the radial artery	<5 seconds	145	97.3	139	94.6	92	92.9	94	94.9
	≥5 seconds	4	2.7	8	5.4	7	7.1	5	5.1
Allen's test for the ulnar artery	<5 seconds	132	88.6	129	87.8	90	90.9	87	87.9
	≥5 seconds	17	11.4	18	12.2	9	9.1	12	12.1
Finger skin temperature (index finger)	≥28°C	92	62.6	95	64.6	62	62.6	57	57.6
	<28°C	55	37.4	52	35.4	37	37.4	42	42.4
Finger skin temperature (little finger)[a]	≥28°C	–	–	–	–	48	48.5	52	52.5
	<28°C	–	–	–	–	51	51.5	47	47.5

Valid column percentages are presented.
[a]Data missing from the Swedish site.

cooling effect can be further demonstrated by the fact that 54% of the study population reported perceived finger coldness and 35% whole-body coldness in the temperature interval that could occur during the winter season in these mines (–20 to – 10°C). There was a positive correlation between hours working in cold conditions and with handheld vibrating tools, suggesting that these exposures often occur in tandem. Finally, the adverse effects of the harsh conditions in this Arctic setting were underlined by 38% of the Arctic open-pit miners in our study reporting having previously sustained local cold injuries.

There is a lot of previous research to suggest that both cold climate and HAV exposure can contribute to neurosensory and vascular dysfunction in the hands. In a cross-sectional study on the working population in Sweden, ambient cooling was associated with a range of neurosensory symptoms in the hands, with exposure-response patterns [6]. Occupational ambient and contact cooling have also been associated with symptoms of carpal tunnel syndrome [15]. HAV is in turn a well-established risk factor for both neurosensory symptoms due to diffuse peripheral neuropathy and carpal tunnel syndrome [9,14]. Regarding vascular symptoms, ambient cold exposure and local cold injury have been associated with RP in both cross-sectional [6,27] and longitudinal studies [8,28]. RP is often associated with exposure to HAV [9] and it has been shown that HAV-exposed workers have a roughly doubled probability of developing RP if they also work in a cold climate [29]. Other authors have investigated possible synergistic effect between cold and HAV exposure in both laboratory [30] and field studies [31], but results have been partly contradicting, which warrants further research on this topic.

Neurosensory and vascular symptoms suggestive of HAV injury were rather common in our study, since about 47% reported some kind of neurosensory symptom in the hands, and 14% reported having RP. These results are in between previous estimates from studies performed in mining settings, where neurosensory and/or vascular HAV injury have been reported in 15% of South African gold miners [32], 18% in Indian limestone miners [33], 24% in U.S. uranium miners [34], 72% in Canadian base metal miners [35], and between 57 to 91% in Hungarian miners [36,37]. The estimates vary widely depending on magnitude and duration of HAV exposure, ambient climate, as well as on the specific criteria for diagnosing HAV injury. However, it is evident that symptoms suggestive of HAV injury are prevalent among workers in the mining industry. In our study, there was also a subset of Arctic open-pit miners (ten subjects) that reported symptoms and signs of carpal tunnel syndrome, and since this is a potentially surgically treatable condition with better prognosis than the other aforementioned outcomes, these workers could benefit if this condition was recognised in an early stage by the occupational health services.

It was beyond the scope of our study to determine if exposure to cold and HAV were causally linked to the reported neurosensory and vascular symptoms and findings, due to the small sample size, limited exposure data, and cross-sectional design of the study. However, in the subset of workers currently exposed to HAV, 25% reported having RP and about 14% neurosensory symptoms and concurrent clinical findings suggestive of nerve injury in the hands. This is of concern since both vascular and neurosensory symptoms are likely to deteriorate with continued exposure. In addition, this practice violates work environment recommendations in both Sweden [38] and Norway [39]. For ambient cooling conditions, there are no strict regulations, but it is likely that cold exposure can aggravate neurosensory and vascular hand symptoms [6,28] and possibly also increase the risk of progression over time. Therefore, symptomatic individuals should preferably avoid intense exposure to ambient and contact cooling conditions. To aid the employers and occupational health services in this challenge, an international standard (ISO 15743:2008) has been developed to guide risk management for cold work [40]. However, this standard appears to see little use in the Scandinavian countries, and the implementation is likely hampered by organisational factors and insufficient resources [41].

There were some apparent differences between the Swedish and Norwegian Arctic miners. Firstly, as demonstrated in Table 1, the age composition of the Swedish sample was skewed towards the lower ages in comparison with the Norwegian sample. There was also a larger proportion of female workers in Sweden that were mostly employed as operators of heavy machinery, while the educational level was higher in the Norwegian mine. As shown in Table 2, there was a tendency (although not statistically significant) towards a higher occurrence of neurosensory symptoms in the Swedish mine. The only symptom that was more prevalent in the Norwegian mine was nocturnal pain and numbness in the hands. Moreover, as shown in Table 3, there was a significantly higher proportion reporting RP in the Swedish mine. In line with these findings, there was a similar tendency towards a higher proportion of abnormal clinical findings among Swedish subjects, as shown in Table 4. This difference may be attributed to more severe working conditions in the Swedish mine in terms of physical exposures, but our exposure measures did not show any significant difference between countries regarding proportion or duration of ambient cooling and HAV exposure. However, we lacked detailed information on exposure intensity, e.g. ambient temperature or wind chill index for cold exposure, and acceleration values (m/s^2) or occurrence of transients (impacts) for HAV exposure. This means that our exposure assessments were rather crude. Alternatively, the difference in symptoms and findings might be explained by a larger proportion of blue-collar workers in the Swedish mine that may have performed more strenuous manual labour. The clinical findings were distributed fairly evenly between the right and left hand (Table 4). We had expected a higher proportion of symptoms in the right hand compared to the left, since it was likely the dominant hand in most subjects and as such potentially more exposed to different adverse physical work environment factors. However, no such difference was found.

Limitations and strengths

Only about half of the intended study sample agreed to participate in our study and we had no information about why some opted out. Thus, there may be a systematic bias in recruitment, where subjects with pronounced exposure to hazardous conditions or those who were symptomatic were more eager to participate. There were also some minor differences in the questionnaires and physical examinations between the Swedish and Norwegian mines that could have made comparisons less valid. The questionnaires had a proportion of missing data that was not negligible, but no imputation was performed. The comparisons between the Swedish and Norwegian sites merely served as rough indications of potential dissimilarities between the mines, but the study was not statistically powered to reveal minor differences. Physical exposures were subjectively rated, and we lacked technical measurements. Also, since all data were cross-sectional, no time relations could be concluded on, which means that we could not establish if occupational exposures had preceded the outcomes. Many subjects were found to have reduced finger skin temperature at the clinical examination, and this is known to reduce the sensory perception [42], especially in those with vasospastic tendencies [43] and can thus yield spurious clinical findings. However, even after warming of the hands, many workers still showed signs of reduced neurosensory function. There were also strengths to our study. We recruited a sample of miners with different work tasks, employed in different types of open-pit mines, which means that the results represent a broad view of working conditions among Arctic miners. Two comprehensive questionnaires offered detailed information on many important parameters, reflecting the general health of these Arctic open-pit miners. Careful physical examination was performed by consultant physicians specialised in occupational and environmental medicine, who followed a detailed protocol and were trained to make similar gradings. This likely reduced the risk of systematic differences in examination techniques and interpretation of clinical findings.

Implications

The results appear to indicate that there is room for substantial improvement in working conditions among Arctic open-pit miners. Since cold exposure was pronounced, improved technical risk assessment and medical surveillance performed by the occupational health services using the ISO 15743:2008 should be encouraged [40]. Risk management strategies should be systematic and begin with efforts to remove hazardous exposures from workers, for instance through automatisation or mechanisation of work tasks currently requiring the use of vibrating handheld tools in cooling conditions [44,45]. If the risks cannot be removed, the exposures should be limited. For cold exposure, this could be achieved by deciding on shorter duration of outdoor work periods, increased number of breaks in a heated environment, sheltering outdoor workplaces from draft and precipitation, as well as covering and heating the driver's compartments of all vehicles. For HAV exposure, it is important to select tools with low acceleration levels, which can be effectively achieved by applying balancing rings in rotating tools and vibration absorbers in impact tools [45]. Tool maintenance is also important to maintain optimal performance and reduce HAV exposure. For large-scale operations, remote-controlled drilling and demolition robots can be employed. In Annex E and D of the standard for measurement and evaluation of human exposure to hand-transmitted vibration (ISO 5349–1:2001), emphasis is put on the fact that climatic conditions and other factors affecting the temperature of the hand or body should be considered in the risk assessment [46]. More specifically, it is stated that workers should use adequate clothing and suitable gloves to keep warm and dry. This part of the standard appears to be commonly overlooked and focus instead given to detailed technical characteristics of vibration exposure. Based on our results, it appears that climatic factors should indeed be given some attention. Finally, if occupational exposures cannot be sufficiently limited, personal protective equipment should be administered. This could include work garments with sufficient thermal insulation, having several pairs of gloves in order to change when they get wet, and padded contact surfaces between vibrating handheld tools and the hand-arm system. Many of these preventive actions require the efforts of specialised occupational hygienists working closely with both employers and employees. Workers could also benefit from basic education and training regarding risks associated with ambient and contact cooling as well as HAV. Finally, there appears to also be a need for increased medical surveillance with regards to HAV exposure, and those with apparent neurosensory or vascular conditions affecting the hands should be recommended to avoid further exposure [38,39].

Conclusions

The study showed that Arctic open-pit miners were commonly exposed to both cooling conditions and hand-arm vibration, more so than the average for workers in Sweden and Norway. They also reported a broad range of neurosensory and vascular symptoms in their hands and had abnormal clinical findings related to the symptoms. These results emphasise the need for additional preventive measures in this setting.

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Disclosure statement

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

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Authors' contributions

AS researched the literature, conceived the study, and formulated the aims. MJ, IL, AA, JW, TN, and HP developed the protocol and collected the data. AA and TN performed clinical examinations. AS, AA, and HP aided in database construction. AS performed data analyses and wrote the first draft of the manuscript. All authors reviewed and edited the manuscript and approved the final version.

Data availability statement

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

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