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Subjective perceptions and psychological distress associated with the deep underground

A cross-sectional study in a deep gold mine in China

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Abstract

This study reports the subjective perceptions and mental state of employees working in the Erdaogou Mine, affiliated with Jiapigou Minerals Limited Corporation of China National Gold Group Corporation (CJEM); these employees are pioneers working at the deepest point below ground in China. The data represent a valuable baseline from which to assess the effects of the environmental factors in the deep-underground on human physiology, psychology, and pathology.

The air pressure, relative humidity, temperature, total γ radiation dose-rate, and oxygen concentration in the CJEM in the aisles in goafs at 4 depths below ground were measured. Study subjects were administered a study-specific questionnaire that included items that targeted factors with potential to affect respondents' health and wellbeing and included the symptom checklist-90-revised (SCL-90-R).

Air pressure, relative humidity, and temperature rose, total γ radiation dose-rate decreased, and there was no change in oxygen concentration with increasing depth below ground. Most (97.2%) respondents had a negative impression of the ambient conditions in the deep-underground space. The most commonly perceived adverse factors included moisture (74.9%), heat (33.5%), and poor ventilation (32.4%). 93.29% of respondents associated $\geq$1 self-reported negative physical symptom with working in the deep-underground space; the most frequent symptoms were being easily tired (48.7%), tinnitus (47.5%), and hearing loss (44.1%). Higher SCL-90-R scores were associated with the perception of >1 adverse factor in the deep-underground, spending >8 hours continuously in the deep-underground space, or working at a depth > 1000 m below ground. >1 perceived adverse factor in the deep-underground and continuously spending >8 hours in the deep-underground space were significant predictors of high SCL-90-R scores.

Adverse factors, including high temperature, humidity, and dim light, may have negative impacts on the physical and psychological health of people who spend long periods of time living and/or working in the deep-underground space.

Abbreviations: CJEM = Jiapigou Minerals Limited Corporation of China National Gold Group Corporation, INTS = interpersonal-sensitivity, IQR = inter-quartile range, NPI = no. of positive items, SCL-90-R = symptom checklist-90-revised.

Keywords: adverse factors, checklist-90-revised, deep-underground, environmental factors, negative physical symptoms

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1. Introduction

Resources at the shallow depths of the earth are gradually becoming exhausted[1]; therefore, history is entering a new era that is focused on the exploration and development of the deep-underground space. Augmenting resources in the shallow depths of the earth by exploiting the deep-underground is cheaper and easier than moving to other planets. Accordingly, early in 1991, the "Declaration of Tokyo" drafted at the International Conference on Urban Underground Space predicted that the 21st century would become the century of developing and utilizing underground space. Consequently, investigating strategies for exploiting the space and resources in the deep-underground has become a government-supported national priority for the future development of science and technology in China.[2]

Currently, coal mines have reached an approximate depth of 1500 m, deep-underground laboratories have reached an approximate depth of 2500 m, and gold mines have reached an approximate depth of 4350 m.[2,3] Experts predict that the use of the deep Earth will reach historical depths, and more people will spend long periods of time living and/or working in the deep-underground space. However, there is a lack of knowledge on the nature of the deep Earth and the factors (eg, low radiation, heat, moist, air pressure, rock, microorganisms, other unknown factors) that may affect the health of humans and other organisms that live and/or work in the deep-underground space. In fact, there is no widely accepted accurate definition of what constitutes the deep underground.

To address the challenges associated with exploiting the deep-underground, Heping Xie, who has been a member of the Chinese Academy of Engineering since 2015, is supervising a team of researchers that are investigating methods to safely and efficiently harness the beneficial elements of the deep Earth.[3] After screening existing mines and tunnels in China to find an ideal research site, a deep-underground laboratory was established in the Erdaogou Mine, which is affiliated with Jiapigou Minerals Limited Corporation of China National Gold Group Corporation (CJEM). The mine is located approximately 300 km southeast of Changchun city in Jilin province in Northeast China and has a mining depth near 1500 m, making it one of the deepest mines in China.

The objective of the present study was to investigate the nature of the deep Earth and its effects on the health of humans. Environmental factors, subjective perceptions, and the mental state of humans working in the mine were recorded. Employees from the CJEM were chosen as study subjects as they represent pioneers, working at the deepest point below ground in China. The data represent a valuable baseline from which to assess the effects of the environmental factors in the deep-underground on human physiology, psychology, and pathology.

2. Materials and methods

This study was conducted between January and April 2018. The study protocol was conducted in accordance with the Declaration of Helsinki and was approved by the ethics committee of West China Hospital, Sichuan University. All study subjects provided written informed consent and could decline to participate if they chose.

2.1. Measurement of environmental factors in the CJEM

The air pressure, relative humidity, temperature (testo480, Testo, AG, Germany); total γ radiation dose-rate (AT1123, ATOMTEX, Belarus); and oxygen concentration

(AR8100, SMART SENSOR, China) in the CJEM in the aisles in goafs at 4 depths (with rock covers of 60 m, 300 m, 750 m, 1470 m) below ground were measured on January to April 2018. For each factor, at each recording site in the aisles with a 50 m distance to the shaft, the average of ≥3 measurements was taken. All measurements were conducted under air ventilation.

2.2. Study subjects

CJEM employees who worked underground were eligible for inclusion in this study. Employees who were not working at the time of the study (eg, on vacation, engaged in learning, on sick-leave) or who were unwilling to participate were excluded from the analyses.

2.3. Questionnaire

Study subjects were administered a study-specific questionnaire that targeted adverse factors in the deep-underground with potential to affect respondents' health and wellbeing and included the symptom checklist-90-revised (SCL-90-R).[4,5]

Items that targeted adverse factors in the deep-underground with potential to affect respondents' health and wellbeing included demographic characteristics such as age, education level, and amount of time spent working in the deep-underground; self-reported negative physical symptoms (palpitations, tinnitus, hearing loss, aural fullness, nasal obstruction, headache, thirst, myalgia, fatigue, cold sweat); questions about adverse factors in the deep-underground (dim light, space, difficulty leaving the deep-underground space, heat, poor ventilation, moisture) that, in the experience of 3 researchers who had spent time in the deep-underground space, may cause discomfort to humans; issues specifically identified by individual respondents; and questions related to the presence of insomnia and its symptoms (trouble sleeping, dreams, waking up during the night or very early in the morning), which were considered relevant as respondents were shielded from sunlight and exposed to dim artificial lighting while working.

The SCL-90-R is a psychometric instrument that assesses the psychology and psychopathology of an individual. The SCL-90-R measures a respondent's self-reported psychopathological symptom intensity on 9 subscales (each comprising 6–13 items) including somatization, compulsion, interpersonal-sensitivity (INTS), depression, anxiety, hostility, terror, paranoia, and psychoticism. The severity of each symptom is rated on a 5-point scale, where 1 = not at all, and 5 = most severe. In 1986, a Chinese version of the SCL-90-R was developed,[5] which has been widely used in diagnosing psychopathologies, measuring the progress and outcome of psychiatric and psychological treatments, or for research purposes in China.[6] In the present study, mean total SCL-90-R scores, the number of items rated ≥2, and the scores for the 9 subscales were calculated, according to a previously published report.[4] In the Chinese population, a positive indication of a psychological problem that needs further exploration is defined as a total SCL-90-R score of ≥160 points, ≥43 positive items, or a score ≥2 on any subscale.

2.4. Statistical methods

Statistical analyses were performed using SPSS 17.0. Descriptive statistics are expressed as frequency, percentage, median and inter-quartile range (IQR), or mean ± standard deviation. Between-measuring site differences in environmental factors were compared using independent samples *t* tests. Differences between the general Chinese male population and CJEM employees in mean scores for each of the 9 subscales of the SCL-90-R were compared using *t*-tests. Respondents were stratified into groups according to age, ≤45 versus >45 years; education, junior middle school or lower versus senior middle school or higher; longest continuous time spent in the deep-underground space, ≤8 versus >8 hours; average time per week spent in the deep-underground space, ≤40 versus >40 hours; length of employment at CJEM, ≤15 versus > 15 years; number of adverse factors perceived in the deep-underground, ≤1 and >1; number of self-reported negative physical symptoms, ≤2 and >2; and insomnia, yes versus no, and univariate and multivariate analyses were used to identify significant predictors of SCL-90-R scores. Pearson correlation analysis was performed to evaluate the potential association between number of perceived adverse factors in the deep underground and number of self-reported negative physical symptoms. $P < .05$ was considered statistically significant.

Table 1

Statistics on the general information of the workers in CJEM.

	n*
Age, yr	
Mean ± SD (min–max)	44.23 ± 7.33 (21–57)
Group, yr ≤45/>45	89/90
Longest continuous staying time in underground, h	
Median (interquartile, min–max)	8 (8–8, 4–60)
Group, h ≤8/>8	144/35
Tenure, h	
Median (interquartile, min–max)	15 (8–20, 1–33)
Group, yr ≤15/>15	97/82
[0,1-2]Depth of working site, m	
Median (interquartile, min–max)	700 (410–1470, 150–1500)
Group, ≤1000/>1000	126/53
Average time of a wk staying in underground, h/wk	
Median (interquartile, min-max)	56 (8–56, 1–72)
Group, ≤40/>40	99/80
Education	
Junior middle school or lower	111
Senior middle school or higher	68
Adverse factor	
Group, ≤1/>1	86/93
Uncomfortable symptom	
Group, ≤2/>2	104/75
Insomnia	
Group, yes/no	122/57

SD = standard deviation.
* Unless indicated otherwise.

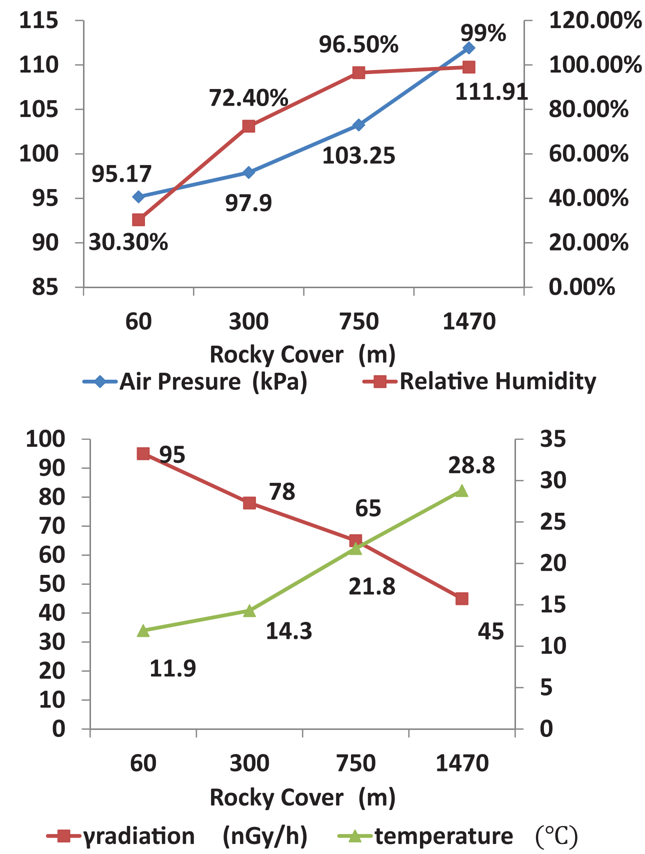

Figure 1. The relationship between environmental parameters (eg, air pressure, relative humidity, temperature total dose rate of γ radiation) with the depth underground. (A) Air pressure and relative humidity rose with increasing depth below ground. (B) Temperature rose, and total γ radiation dose-rate decreased with increasing depth below ground.

3. Results

3.1. Study subjects

A total of 199 questionnaires were distributed and returned. Twenty questionnaires with duplicate responses were excluded, and 179 (89.95%) valid questionnaires were included in this analysis. Demographic characteristics of the respondents are summarized in Table 1. As mining is a male-dominated sector, all respondents were male. Respondents worked underground at depths ranging from 140 to 1470 m; 29.05% (52/179) of respondents worked at depths >1000 m below ground. Mean age of respondents was 44.23 ± 7.33 years (range: 21–57 years). Median longest continuous time spent in the deep-underground space, time per week spent in the deep-underground space, and length of employment at CJEM were 8 hours (IQR: 8–8, min, max: 4, 60 hours), 56 hours per week (IQR: 8–56; min, max: 1, 72 hours per week), and 15 years (IQR: 8–20; min, max: 1, 33 years), respectively.

3.2. Environmental factors in the CJEM and subjective perceptions of CJEM employees

Measurements of the environmental factors in the CJEM are shown in Figure 1. The air pressure, relative humidity, and temperature rose, total γ radiation dose-rate decreased, and there was no change in oxygen concentration (range 20.8%–21.4% at the 4 depths) with increasing depth below ground.

Adverse factors perceived in the deep-underground, self-reported negative physical symptoms, and prevalence of insomnia and its symptoms in the respondents are summarized in Table 2. 97.2% (174/179) of respondents had a negative impression of their ambient underground conditions. 75.98% (136/179) of respondents were most worried about safety while working in the deep-underground space. 75.98% (136/179) of respondents reported that ≥1 adverse factor caused them discomfort while working in the deep underground space, including moisture (74.86% [134/179]), heat (33.52% [60/179]), poor ventilation (32.4% [58/179]), dim light (26.82% [48/179]), and narrow space (18.99% [34/179]). Only 7.26% (13/179) reported difficultly leaving the deep-underground space (Table 2).

93.29% (167/179) of respondents associated ≥1 self-reported negative physical symptom with working in the deep-underground space, including being easily tired (30.72% [55/179]), tinnitus (47.48% [85/179]), hearing loss (44.13% [79/179]), thirst (25.69% [46/179]), aural fullness (21.78% [39/179]), myalgia (21.22% [38/179]), palpitations (18.44% [33/179]), headache (17.87% [32/179]), nasal obstruction and breathing difficulties (11.73% [21/179]), and cold sweats (9.49% [17/179]) (Table 2).

68.15% (122/179) of respondents associated suffering from insomnia with working in the deep-underground space, reporting trouble sleeping (30.32% [37/122]), dreams (27.05% [33/122]), waking up during the night (22.95% [28/122]) or very early in the morning (57.37% [70/122]) (Table 2).

There was a positive correlation between number of perceived adverse factors in the deep underground and number of self-reported negative physical symptoms ($r = 0.816$, $P < .001$).

Table 2

Adverse factors perceived by respondents in the deep-underground, self-reported negative physical symptoms, and prevalence of insomnia and its symptoms.

Adverse factors		Physical symptoms self-reported	
Moisture	74.86% (134/179)	Being easily tired	30.72% (55/179)
Dim light	26.81% (48/179)	Hearing loss	44.13% (79/179)
Narrow space	18.99% (34/179)	Tinnitus	47.49% (85/179)
Heat	33.52% (60/179)	Myalgia	21.22% (38/179)
Poor ventilation	32.4% (58/179)	Thirst	25.69% (46/179)
Difficult to leave DUG	7.26% (13/179)	Cold sweat	9.49% (17/179)
Insomnia	68.15% (122/179)	Headache	17.87% (32/179)
Trouble sleeping	30.32% (37/122)	Nasal obstruction	11.73% (21/179)
Dreaminess,	27.05% (33/122)	Palpitation	18.4% (33/179)
Wake up in the middle of night	22.95% (28/122)	Breathing difficulties	11.73% (21/179)
Wake up in the early morning	57.37% (70/122)	Aural fullness	21.8% (39/179)

3.3. Prevalence of psychological problems in CJEM employees and comparison of SCL-90-R scores with national norms

Among survey respondents, 22 (12.3%, 95% confidence interval 7.4%–17.1%) had a positive indication of a psychological problem that needed further exploration. Differences between survey respondents and the general Chinese male population in the number of positive items on the SCL-90-R and the mean scores for each of the 9 subscales are shown in Table 3. The number of positive items and the mean scores for compulsion, INTS, depression, paranoia, and psychosis were significantly lower for survey respondents compared to the national norm; there were no significant differences in means scores for somatization, anxiety, hostility, or terror. These findings suggest that the reported overall mental health of the survey respondents was better than the overall mental health of the general Chinese male population.

3.4. Univariate analysis of factors influencing SCL-90-R scores

Results of the univariate analysis are summarized in Table 4. Mean total SCL-90-R score, number of positive items, and scores for the 9 subscales were compared between survey respondents stratified according to age, education, working depth below ground, longest continuous time spent underground, length of employment at CJEM, number of perceived adverse factors in the deep underground, number of self-reported negative physical symptoms, and presence/absence of insomnia.

All variables, except for age and education, correlated with SCL-90-R scores. Mean total SCL-90-R score, number of positive items, and scores for the 9 subscales were significantly higher in respondents who perceived >1 adverse factor in the deep underground. Mean total SCL-90-R score, number of positive items, and scores for the 9 subscales except compulsion were significantly higher for respondents who continuously spent >8 hours in the deep-underground space or who worked at the depth > 1000 m below ground. Mean total SCL-90-R score, number of positive items, and scores for the 9 subscales except hostility and terror were significantly higher for respondents who reported insomnia. Mean total SCL-90-R score and scores for the 9 subscales except INTS were significantly higher for respondents with >2 self-reported negative physical symptoms. Scores for the terror and paranoia subscales were significantly higher for respondents who had been employed at CJEM for >15 years.

3.5. Multivariate analysis of factors influencing the SCL-90-R scores

Results of the multivariate analysis are summarized in Table 5. >1 perceived adverse factor in the deep underground was a significant predictor of high SCL-90-R scores, including total SCL-90-R score, number of positive items, and scores for the 9 subscales. Continuously spending >8 hours in the deep-underground space was a significant predictor of high SCL-90-R scores, including total score, number of positive items, and scores on the somatization, compulsion, and terror subscales.

Table 3

Comparison of SCL-90-R scores between survey respondents and the general Chinese male population.

Dimensions	Practical score mean ± SD	Norm, mean ± SD	*t*	*P*
Somatization	1.35 ± 0.63	1.37 ± 0.48	−0.44	.65
Compulsion	1.30 ± 0.58	1.62 ± 0.58	−7.39	<.001
INTS	1.25 ± 0.54	1.65 ± 0.51	−9.93	<.001
Depression	1.26 ± 0.55	1.50 ± 0.59	−5.90	<.001
Anxiety	1.26 ± 0.54	1.39 ± 0.43	−0.79	.48
Hostility	1.30 ± 0.60	1.48 ± 0.56	−0.49	.63
Terror	1.18 ± 0.47	1.23 ± 0.37	−1.36	.18
Paranoia	1.23 ± 0.52	1.46 ± 0.59	−6.0	<.001
Psychosis	1.22 ± 0.51	1.32 ± 0.44	−2.6	.010
NPI	14.61 ± 23.63	25.68 ± 18.79	−6.27	<.001

INTS = interpersonal-sensitivity, NPI = no. of positive items.

Table 4

Univariate analysis of factors influencing SCL-90-R scores.

	Somatization	Compulsion	INTS	Depression	Anxiety	Hostility	Terror	Paranoia	Psychosis	Total average	Positive items
Insomnia											
Yes	1.44 ± 0.70	1.39 ± 0.65	1.30 ± 0.59	1.32 ± 0.61	1.32 ± 0.59	1.36 ± 0.67	1.21 ± 0.51	1.28 ± 0.57	1.28 ± 0.58	1.33 ± 0.58	17.57 ± 23.93
No	1.15 ± 0.39	1.12 ± 0.30	1.14 ± 0.40	1.13 ± 0.39	1.13 ± 0.38	1.16 ± 0.41	1.11 ± 0.38	1.12 ± 0.29	1.11 ± 0.29	1.44 ± 0.36	8.38 ± 22.22
t	12.33	17.32	4.76	6.37	7.27	2.71	8.51	11.41	16.43	8.06	5.57
P	.001	<.001	.030	.013	.008	.100	.120	.001	<.001	.005	.019
Longest continuous staying time in underground											
≤8	1.27 ± 0.56	1.25 ± 0.56	1.20 ± 0.51	1.20 ± 0.51	1.20 ± 0.50	1.24 ± 0.54	1.11 ± 0.37	1.18 ± 0.47	1.18 ± 0.48	1.21 ± 0.48	11.29 ± 19.98
>8	1.84 ± 0.81	1.67 ± 0.63	1.61 ± 0.74	1.64 ± 0.75	1.62 ± 0.69	1.72 ± 0.84	1.60 ± 0.75	1.58 ± 0.73	1.54 ± 0.7	1.66 ± 0.69	36.00 ± 32.66
t	−4.48	−3.49	−3.58	−3.77	−3.72	−3.90	−5.09	−3.70	−3.31	−4.10	−5.21
P	.001	.292	.01	<.001	.001	<.001	<.001	<.001	.003	.001	<.001
No. of adverse factors											
≤1 (86)	1.17 ± 0.41	1.17 ± 0.47	1.16 ± 0.41	1.15 ± 0.40	1.14 ± 0.34	1.18 ± 0.44	1.12 ± 0.35	1.13 ± 0.34	1.13 ± 0.40	1.15 ± 0.38	8.86 ± 20.84
>1 (93)	1.51 ± 0.74	1.43 ± 0.64	1.33 ± 0.63	1.35 ± 0.65	1.38 ± 0.65	1.41 ± 0.71	1.24 ± 0.56	1.32 ± 0.63	1.30 ± 0.59	1.37 ± 0.61	19.92 ± 24.90
t	3.61	3.06	2.14	2.47	3.04	2.60	1.75	2.58	2.22	8.67	3.21
P	<.001	.002	.02	.007	<.001	.004	.010	<.001	.002	.004	.002
No. of physical symptoms											
≤2	1.24 ± 0.47	1.23 ± 0.49	1.19 ± 0.45	1.19 ± 0.47	1.19 ± 0.42	1.21 ± 0.47	1.12 ± 0.34	1.16 ± 0.38	1.16 ± 0.42	1.20 ± 0.42	11.48 ± 21.93
>2	1.50 ± 0.77	1.40 ± 0.66	1.33 ± 0.64	1.35 ± 0.65	1.36 ± 0.66	1.42 ± 0.73	1.26 ± 0.60	1.32 ± 0.65	1.29 ± 0.61	1.37 ± 0.63	18.95 ± 26.33
t	2.82	2.11	1.66	1.92	2.22	2.29	2.10	2.14	1.72	2.27	2.11
P	<.001	.015	.057	.039	.003	.007	.001	.004	.006	.013	.051
Tenure											
≤15 yr	1.29 ± 0.60	1.24 ± 0.49	1.19 ± 0.49	1.20 ± 0.53	1.23 ± 0.53	1.22 ± 0.52	1.16 ± 0.40	1.20 ± 0.51	1.17 ± 0.42	1.22 ± 0.50	12.50 ± 24.16
>15 yr	1.49 ± 0.70	1.41 ± 0.61	1.34 ± 0.61	1.34 ± 0. 59	1.35 ± 0.62	1.45 ± 0.72	1.28 ± 0.41	1.32 ± 0.60	1.37 ± 0.59	1.37 ± 0.59	20.48 ± 24.72
t	−1.89	−1.83	−1.63	−1.44	−1.27	−2.25	−1.44	−1.30	−1.31	−1.66	−1.96
P	.380	.170	.120	.170	.320	.043	.018	.150	.130	.300	.380
Depth											
≤1000 m	1.33 ± 0.62	1.27 ± 0.58	1.23 ± 0.55	1.23 ± 0. 57	1.23 ± 0.52	1.27 ± 0.57	1.14 ± 0.40	1.20 ± 0.54	1.22 ± 0.52	1.25 ± 0.52	12.71 ± 22.14
>1000	1.57 ± 0.72	1.54 ± 0.66	1.44 ± 0.63	1.46 ± 0.62	1.46 ± 0.66	1.54 ± 0.77	1.40 ± 0.69	1.43 ± 0.60	1.34 ± 0.61	1.47 ± 0.61	26.72 ± 28.48
t	−4.45	3.49	−3.59	−3.77	−3.72	−3.90	−5.09	−3.70	−3.32	−4.14	−5.2
P	.001	.292	.001	<.001	0.001	<.001	<.001	<.001	.003	.001	<.001

INTS = interpersonal-sensitivity.

4. Discussion

Knowledge of the nature of the deep Earth and its' potential effect on humans and other organisms is prerequisite for further developing and utilizing the resources and space in the deep underground. Exploitation of the deep-underground is currently limited by technology and a lack of biomedical research, which are required to allow humans to safely exploit the beneficial elements of the deep Earth.[3] The present study makes a critical contribution to bio-medical research by investigating the physiological and psychological responses of humans living and working in the deep-underground space. This exploratory study established baseline values for environmental factors and the subjective perceptions of employees working in the CJEM. It is one of the first studies exploring the potential effects of factors in the deep-underground environment on human health and serves as a starting point to developing further research initiatives in this area.

Table 5

Multivariate analysis of factors influencing SCL-90-R scores.

	Somatization		Compulsion		INTS		Depression		Anxiety	
	β	*P*	β	*P*	β	*P*	β	*P*	β	*P*
Insomnia (yes)	0.127	.935	0.092	.846	0.098	.254	0.119	.974	0.102	.222
Longest continuous staying time in underground (>8)	0.417	.004	0.254	.048	0.123	.148	0.125	.138	0.107	.197
No. of adverse factors (>1)	0.782	<.001	0.738	<.001	0.784	<.001	0.868	<.001	0.916	<.001
No. of physical symptoms (>2)	0.113	.110	0.105	.935	0.03	.726	0.320	.802	0.035	.683
Depth >1000	−0.038	.909	0.048	.633	0.027	.79	0.003	.974	0.020	.810

	Hostility		Terror		Paranoia		Psychosis		Total average		Positive items	
	β	*P*	β	*P*	β	*P*	β	*P*	β	*P*	β	*P*
Insomnia (yes)	0.093	.270	0.106	.935	0.127	.233	0.26	.041	0.136	.310	0.134	.195
Longest continuous staying time in underground (>8)	0.156	.061	0.288	.019	0.116	.061	0.163	.103	0.58	<.001	13.68	.017
No. of adverse factors (>1)	0.950	<.001	0.732	<.001	0.863	<.001	0.812	<.001	0.837	<.001	26.61	<.001
No. of physical symptoms (>2)	0.046	.591	0.130	.100	0.290	.065	0.446	.586	0.072	.549	1.420	.256

INTS = interpersonal-sensitivity.

Findings from the present study showed air pressure, temperature, and humidity increased with increasing depth below ground. When the rocky cover reached 760 m, the relative humidity was >90%. Despite ventilation, the temperature still approached 30°C in the aisle of a goaf at 1470 m below ground; however, oxygen concentration did not obviously change. As in other deep-underground laboratories,[7] γ radiation dose-rate decreased to <one-half of the value at the surface. The vast majority (97.2%) of the CJEM employees that responded to the survey had a negative impression of their ambient underground conditions, identifying moisture (74.9%) as the most troubling adverse factor in the deep-underground space, followed by heat (33.5%), poor ventilation (32.4%), dim light, and the narrow space. Overall, <10% of respondents reported difficultly leaving the deep-underground space.

Previous reports demonstrated changes in cell growth, enzyme activity, and sensitivity to factors that cause genetic damage in prokaryote and eukaryote cells maintained in low levels of background radiation.[3,8–10] Although the biological impact of low levels of background radiation in humans remains to be elucidated, poor working conditions are known to cause stress and affect the psychological and physical health of workers.[11] In the present study, 93.29% of survey respondents associated at least 1 negative physical symptom with working in the deep-underground space, and there was a positive correlation between number of perceived adverse factors in the deep-underground and self-reported negative physical symptoms. Approximately one-half of survey respondents indicated that they were easily tired when working in the deep-underground space. Aural symptoms were also obvious; with approximately one-half of respondents suffering from tinnitus and hearing loss, and more than one-fifth experiencing aural fullness. One-fourth of respondents felt thirsty while working in the deep-underground space, approximately one-fifth of respondents suffered from headache, myalgia, or palpitations, and one-tenth of respondents experienced nasal obstruction, difficulty breathing, and cold sweats.

However, it is unclear whether the respondents self-reported negative physical symptoms were directly associated with adverse factors in the deep-underground space. A previous study from Sweden showed employees working in underground factories suffered from headaches, fatigue, and insomnia; however, blood analyses showed no differences from workers in an above ground workplace and no differences 8 years later when the negative complaints had disappeared.[12] In the present study, dyspnea may have been psychogenic, as there was no change in oxygen concentration with increasing depth below ground.

Despite reporting negative physical symptoms, respondents overall mental state did not appear to be affected by adverse factors in the deep underground space. The number of positive items on the SCL-90-R and scores for various symptoms of psychopathology such as compulsion, INTS, depression, paranoia, and psychosis were better for the respondents compared to the national average for Chinese men, and scores for somatization, anxiety, hostility, and terror were the same as the national norm.[13] However, higher SCL-90-R scores were associated with more perceived adverse factors in the deep underground and longer continuous time spent in the deep-underground space. A previous study in petrochemical workers in Taiwan revealed that stressors in the work environment were associated with occupational non-fatal injuries.[14] In the present study, exposure to potential stressors in the deep underground space, including moisture, heat, poor ventilation, dim light, and narrow spaces, for a prolonged period of time had potential to cause physical and psychological disorders in survey respondents. Interestingly, although variables such as insomnia, number of self-reported negative physical symptoms, working depth, and length of employment at CJEM were significantly associated with SCL-90-R scores in the univariate analysis, there was no association in the multivariate analyses. This suggests these variables may have been indirectly related to SCL-90-R scores or the analyses may have been limited by the small sample size.

In the present study, approximately 70% of survey respondents associated suffering from insomnia with working in the deep-underground space, reporting trouble sleeping, and waking up very early in the morning as their main complaints. In contrast to these findings, a previous study found that underground workers had a higher diurnal variation in melatonin, slept longer, and fell asleep more easily than aboveground workers.[15] Evidence suggests that lack of exposure to natural sunlight can affect the sleep-wake cycle.[12] In the present study, psychogenic factors caused by survey respondents' anxiety about their working environment, physical symptoms, or mental disorders may have had a negative effect on sleep quality. Importantly, survey respondents with insomnia had higher scores on the SCL-90-R.

This study was associated with several limitations. First, survey questions pertained to factors in the deep-underground that were considered adverse based on the experience of 3 researchers who had spent time in 1 goaf. These experiences may not be generalizable across the entire deep-underground space. Second, some potentially important environmental factors, including noise, dust, and air composition were not considered. Third, this was a cross-sectional study; therefore, interactions between adverse factors, self-reported negative physical symptoms, insomnia, and psychopathology could not be evaluated. Fourth, the health-related quality of life and socioeconomic status (income, marital status, being an only child) of the survey respondents were not considered. Fifth, perceptions concerning adverse factors and physical symptoms were based on researchers self-experience and survey respondents' self-report, respectively. Finally, the sample size was small. Despite these limitations, findings from the present study should be augmented by a larger scale study that investigates a greater number of parameters and has a more rigorous design

The present study revealed that most underground workers at the CJEM had a negative impression of the ambient conditions in the deep-underground space. The most commonly perceived adverse factors included moisture, heat, and poor ventilation. The majority of workers associated several self-reported negative physical symptoms with working in the deep-underground space. >1 adverse factor in the deep underground and continuously spending >8 hours in the deep-underground space were significant predictors of high SCL-90-R scores. These data imply that adverse factors, including high temperature, humidity, and dim light, may have negative impacts on the physical and psychological health of people who spend long periods of time living and/or working in the deep-underground space.

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References

[1] Ranjith PG, Zhao J, Ju M, et al. Opportunities and challenges in deep mining: a brief review. Engineering 2017;3:546–51.
[2] Xie H, Gao F, Ju Y, et al. Novel idea and disruptive technologies for the exploration and research of deep earth. Adv Eng Sci 2017;49:1–8.
[3] Xie H, Liu J, Gao M, et al. The research advancement and conception of the deep-underground medicine. J Sichuan Univ (Med Sci Ed) 2018;49:162–8.
[4] Derogatis LR. SCL-90: Administration, Scoring and Procedures Manual-I for the R (revised) Version and Other Instruments of the Psychopathology Rating Scales Series. Chicago, IL, USA: Johns Hopkins University School of Medicine; 1977.
[5] Wang ZY. Symptom checklist (SCL-90). Shanghai Psychiatry 1984;2:68–70.
[6] Liu X, Jiang D, Hou Z, et al. Mental health of the prison medical workers (PMWs) and influencing factors in Jiangxi, China. Int J Environ Res Public Health 2017;14:1459.
[7] Lampe N, Breton V, Sarramia D, et al. Understanding low radiation background biology through controlled evolution experiments. Evol Appl 2017;10:658–66.
[8] Planel H, Soleilhavoup JP, Tixador R, et al. Influence on cell proliferation of background radiation or exposure to very low, chronic gamma radiation. Health Phys 1987;52:571–8.
[9] Smith GB, Grof Y, Navarrette A, et al. Exploring biological effects of low level radiation from the other side of background. Health Phys 2011;100:263–5.
[10] Kawanishi M, Okuyama K, Shiraishi K, et al. Growth retardation of Paramecium and mouse cells by shielding them from background radiation. J Radiat Res 2012;53:404–10.
[11] Amponsah-Tawiah K, Leka S, Jain A, et al. The impact of physical and psychosocial risks on employee well-being and quality of life: the case of the mining industry in Ghana. Safety Sci 2014;65:28–35.
[12] Chee-Kiong S, Christopoulos GI, Roberts AC, Lee EH. Human-centered development of underground work spaces. Paper presented at: International Scientific Conference "underground Urbanisation as a Prerequisite for Sustainable Development 2016.
[13] Jin H, Wu WY, Zhang YM. Study on SCL-90 assessment of normal Chinese in China. Chin J Nerv Ment Dis 1986;12:260–3.
[14] Li CY, Chen KR, Wu CH, et al. Job stress and dissatisfaction in association with non-fatal injuries on the job in a cross-sectional sample of petrochemical workers. Occup Med 2001;51:50–5.
[15] Küller R, Wetterberg L. The subterranean work environment: impact on well-being and health. Environ Int 1996;22:33–52.