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Physical symptoms and mental health status in deep underground miners

A cross-sectional study

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Abstract

The aim of the present study was to reveal the physical symptom changes and their correlations with mental health status in deep underground miners.

A total of 286 deep underground miners completed a cross-sectional questionnaire study at China Pingmei Shenma mine complex. The questionnaire included sociodemographics, self-reported physical symptoms, underground adverse environmental factors, and the Symptom Checklist-90-Revised (SCL-90-R). Five environmental parameters of 1 deep mine were also measured.

Data from 266 valid questionnaires were analyzed. The 3 most frequent complaints about underground adverse conditions were moisture [62.03% (165/266)], dim light [45.86% (122/266)], and high temperature [42.11% (112/266)]. Fatigue [40.22% (107/266)], hearing loss [34.96% (93/266)], and tinnitus [31.58% (84/266)] were reported to be the three most common physical symptoms. Insomnia was reported in 204 participants (76.69%) mainly due to the difficulty of falling asleep [42.35% (84/204)] and dreams [39.70% (81/204)]. Mean scores of SCL-90-R subscales including somatization, anxiety, phobic anxiety, psychoticism, and paranoid ideation were elevated compared to Chinese norms, while there was diminished interpersonal sensitivity. Univariate analyses indicated that the 3 most common physical symptoms were associated with poorer SCL-90-R scores. With increasing depth below ground, air pressure, relative humidity, CO_2 concentration and temperature rose, while total gamma radiation dose-rate decreased.

The physical and mental health status of deep underground miners was poorer than the general Chinese male population. Some adverse environmental factors were identified that may have influenced health status. Measures are suggested to improve the deep underground working environment.

Abbreviations: CPSG = China Pingmei Shenma Group, DUG = deep underground, IQR = interquartile range, I-S = interpersonal sensitivity, NPI = number of positive item, O-C = obsessive compulsiveness, P-A = phobic anxiety, P-I = paranoid ideation, SCL-90-R = Symptom Checklist-90-Revised.

Keywords: deep underground, physical symptoms, mental health

1. Introduction

Deep underground (DUG) mining is increasingly being performed as the resources of the shallower earth are gradually exhausted.[1,2] So far, miners have reached 1500 m in coal mines and over 4000 m in nonferrous metal mines.[1–4] Such extreme environments could impact the entire psychologic and physiologic systems of miners who remain DUG for a long time, and multiple factors may be involved.[3] However, little is known about the environmental factors that affect the health of humans and other organisms who live or work DUG. To identify

Editor: Massimo Tusconi.

HX and JL contributed equally to the work.

This project was funded by the special funds for deep underground medical research of West China Hospital, Sichuan University (grant no: YB2018002),1.3.5 project for disciplines of excellence, West China Hospital, Sichuan University (grant no: ZYJC18016), Sichuan International Technological innovation Cooperation Project (grant no: 2018HH0159), Open fund of Key Laboratory of Deep Earth Science and Engineering (Sichuan University), Ministry of Education (grant no: DESEYU 201902), and National Natural Science Foundation of China (grant no: 51822403).

The authors have no funding and conflicts of interest to disclose.

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How to cite this article: Xie H, Liu J, Gao M, Liu Y, Ma T, Lu Y, Li C, Wang M, Zhang R, Wu J, Zou J, Liu S, Li W. Physical symptoms and mental health status in deep underground miners: a cross-sectional study. Medicine 2020;99:9(e19294).

Received: 11 August 2019 / Received in final form: 4 January 2020 / Accepted: 26 January 2020

http://dx.doi.org/10.1097/MD.0000000000019294

potential biologic effects in DUG conditions, DUG laboratories have been built around the world since the 1st pioneering establishment was completed in 1964.[1,3] Previously, a few basic studies of the growth and metabolism of cultured cells were conducted in DUG labs with inspiring results discovered.[2,3] Human studies, mainly epidemiologic studies, have also been performed on the health status of miners, including quality of life[5–7] and cigarette smoking.[8] However, these studies did not differentiate between deep mines and shallower ones. Mental health has been an important focus,[5,7,9,10] because it is crucial for miners to work effectively and productively.[4]

China has the biggest population of underground and DUG miners in the world. Existing studies[3,5,9,11] in China suggest that long-time underground working is probably associated with poorer mental health status. Although efforts have been made to investigate possible strategies to minimize the disadvantageous effects on mental health of working miners,[11] no study has exclusively focused on the underground mental health status and physical symptoms in DUG environments.

A previous study explored the environmental factors in DUG on human health in a gold mine; Erdaogou mine of Jiapigou Minerals Limited Corporation of China National Gold Group Corporation (CJEM).[12] This found that the adverse factors of deep mine might have negative effect on the physical and psychologic health of miners, especially for quality of sleep. The present study replicates this with a larger sample of coal miners to study physical and mental health status amongst DUG coal miners and obtain objective measures of the DUG physical environment.

2. Materials and methods

2.1. Study design and subjects

This was a questionnaire-based cross-sectional study conducted at the China Pingmei Shenma Group (CPSG) mine. The study was in accordance with the Declaration of Helsinki and was approved by the ethics committee of West China hospital, Sichuan University. Written consent forms were collected from all participants.

The CPSG was chosen as the study site, because it is one of the largest coal mine complexes in China, located in Henan Province. The deepest mines in CPSG have reached 1500 m below ground. All miners working during the days when data were collected who worked in the deep mine below 600 m were included in the study. Participants received careful explanations regarding questionnaire completed and questionnaires were returned to the interviewers once completed. Additionally, 5 environmental parameters of 1 deep mine of CPSG were measured.

2.2. Study questionnaire

A specially prepared questionnaire was used, which was consisted of 4 parts (demographic information, Symptom Checklist-90-Revised [SCL-90-R],[13,14] self-reported physical symptoms and underground adverse environmental factors). Demographic information included gender, age, education level, service years, mean working depth, mean time per week underground, and longest continuous time underground. The SCL-90-R Chinese version[13,14] was used to assess the mental health status of all participants. It contains 9 subscales (6–13 items each) including somatization, obsessive compulsiveness (O-C), interpersonal sensitivity (I-S), depression, anxiety, hostility, phobic anxiety (P-A), paranoid ideation (P-I), and psychoticism. The details have been described in previous research.[12] Briefly, the severity of each symptom is rated by a 5-point scale, from 1 = not at all, to 5 = most severe. Based on previous studies, the total SCL-90-R scores, number of items ≥2 and scores of the 9 subscales were calculated, respectively.[12] A total SCL-90-R score ≥160 points, the number of positive items (NPIs) ≥43, and a score on any subscale ≥2 are considered to be signs of possible mental health problems in the Chinese population.[13,14]

To investigate possible physical symptoms and underground adverse environmental factors related to DUG environment, 3 researchers descended multiple times into a mine with a rocky cover of 1470 m[12] and recorded their symptoms. According to their detailed documentation, physical symptoms related to the DUG environment included palpitations, tinnitus, hearing loss, aural fullness, nasal obstruction, headache, thirst, myalgia, unusual sweating, easily fatigued, insomnia. They also noted potential adverse physical features of the environment (dim light, narrow space, higher temperature, poor ventilation, difficult to leave DUG, and moisture).

2.3. Measurement of environmental parameters of the 12th mine in CPSG

As reference, the environmental parameters in the aisles of the 12th mine of CPSG were measured from 1 to 6 November 2018. Five environmental parameters (air pressure, relative humidity, temperature, total gamma radiation dose-rate and CO_2 concentration) (Testo 480; Testo, AG, Lenzkirch, Germany) were measured 7 times. The depths of measurements were from 0 to 932 m with a vertical interval from 5 to 243.5 m underground. It is noteworthy that the measurements were conducted under air ventilation.

2.4. Statistical analysis

Statistical analyses were performed with SPSS version 17.0 and $P < .05$ was set as the level of significance. Descriptive statistics were used to summarize the sample characteristics and expressed as frequency, percentage, median, and interquartile range (IQR), or mean ± standard deviation. Comparisons between 2 groups were conducted using an independent samples' t test. Multivariate comparisons were made with linear regression analysis. Variables that did not influence SCL-90 scores in univariate tests were removed. The remaining variables were included in linear regression to predict the nine SCL-90-R subscales, the total average, and the NPIs. Multivariate logistic regression analyses were also calculated to identify the relevance of main factors and sleep. To evaluate the possible association between the numbers of adverse factors and subjectively uncomfortable symptoms in DUG, Pearson correlations were used.

3. Results

3.1. Basic demographic features of the participants

In total, 286 participants of CPSG were enrolled and 266 (93.01%) valid questionnaires were collected and analyzed. Basic demographic characteristics of the participants are summarized in Table 1. All participants were males. All worked at a depth of at least 600 m and 58.27% (155/266) of them worked in DUG with the depth at least 1000 m. Mean time staying underground per week was 30 hours (IQR 22–39, min–max: 3–72), mean longest continuous time staying underground was 8 hours (IQR

Table 1

The demographic characteristics of the workers of CPSG.

	N
Age, yr	
Median (interquartile, min–max)	40.00 (35–46, 25–56)
Group, yr ≤40/>40	138 (51.88%)/128 (48.12%)
Longest continuous staying time in underground, h	
Median (interquartile, min–max)	8 (8–10, 4–36)
Group, h ≤8/>8	139 (52.26%)/127 (48.74%)
Length of employment, yr, median (interquartile, min–max)	15 (10–20,2–33)
Group, yr ≤15/>15	146 (54.89%)/120 (45.11%)
Depth of working site, m, median (interquartile, min–max)	1000 (800–1100, 600–1100)
Group, ≤1000/>1000	111 (41.73%)/155 (58.27%)
Average time of a week staying in underground, h/wk	
Median (interquartile, min–max)	30 (22–39, 3–72)
Group, ≤40/>40	128 (48.12%)/138 (51.88%)
Education	
Junior middle school or lower	122 (45.86%)
Senior middle school or higher	144 (54.14%)

CPSG = China Pingmei Shenma Group.

8–10, min–max: 4–36) and the mean length of employment in DUG was 15 years (IQR 10–20, min–max: 2–33). Participants with an education level of senior middle school or higher accounted for 54.14% (144/266) of the sample.

3.2. Physical symptoms and adverse factors in DUG

Physical symptoms and adverse factors related to DUG are listed in Table 2. The 3 most frequent adverse factors mentioned were moisture (62.03% [165/266]), dim light (45.86% [122/266]), and high temperature (42.11% [112/266]). Additionally, 98.3% (263/266) of participants reported at least 1 self-reported uncomfortable physical symptom when they were working in the deep area. The 3 leading symptoms were fatiguing easily (40.22% [107/266]), hearing loss (34.96% [93/266]), and tinnitus (31.58% [84/266]). Insomnia to some extent was reported in 204 (76.69%) subjects and the most common issues were having trouble in falling asleep (42.35% [84/204]), followed by dreams (39.70% [81/204]), waking up early in the morning (29.9% [61/204]), and waking up in the middle of night (22.55% [46/204]).

A positive correlation was found between the number of adverse factors mentioned and self-reported physical symptoms ($r = 0.586$, $P < .001$). Binary logistic regression found that the number of physical symptoms (odds ratio [OR] = 1.89, $P = .004$) and longest continuous time staying underground (OR = 1.34, $P = .007$) were significant factors affecting sleep quality.

3.3. Mental health status of participants (SCL-90-R)

Participants' mean scores on SCL-90-R subscales were compared to Chinese National Norms as summarized in Table 3. Compared to the norms, miners scored significantly higher on somatization ($P < .001$), anxiety ($P < .001$), P-A ($P < .001$), psychoticism

Table 2

Self-reported adverse factors and physical symptoms by DUG miners.

		Physical symptoms self-reported	
Adverse factors			
Moisture	62.03% (165/266)	Fatigue easily	40.22% (107/266)
Dim light	45.86% (122/266)	Hearing loss	34.96% (93/266)
Narrow space	35.34% (94/266)	Tinnitus	31.58% (84/266)
Higher temperature	42.11% (112/266)	Myalgia	19.54% (52 /266)
Poor ventilation	28.57%(76/266)	Thirst	19.17% (51 /266)
Difficult to leave DUG	7.5%(20/266)	Unusual sweating	18.42% (49/266)
Insomnia	Yes/no (204/62)	Headache	15.41% (41/266)
Trouble sleeping	42.35% (84/204)	Nasal obstruction	10.15% (27/266)
Dreams	39.7% (81/204)	Palpitation	22.93% (61/266)
Waking in the middle of night	22.55% (46/204)	Breathing difficulties	9.4% (25/266)
Waking early morning.	29.9% (61/204)	Aural fullness	19.17%(51/266)

DUG = deep underground.

Table 3

Respondents' scores on dimensions of SCL-90-R (N = 266).

Dimensions	Practical score, mean ± SD	Norm, mean ± SD	*T*	*P*
Somatization	1.72 ± 0.76	1.38 ± 0.49	7.29	<.01
O-C	1.67 ± 0.76	1.66 ± 0.61	1.02	.31
I-S	1.53 ± 0.72	1.66 ± 0.64	−2.87	.04
Depression	1.59 ± 0.75	1.51 ± 0.60	1.79	.08
Anxiety	1.60 ± 0.77	1.41 ± 0.44	4.01	<.01
Hostility	1.55 ± 0.73	1.48 ± 0.56	1.68	.75
P-A	1.42 ± 0.67	1.23 ± 0.41	4.6	<.01
P-I	1.49 ± 9.67	1.43 ± 0.57	0.73	.47
Psychoticism	1.49 ± 0.69	1.29 ± 0.42	4.8	<.01
NPI	31.68 ± 28.66	25.68 ± 18.79	2.41	.01

I-S = interpersonal sensitivity, NPI = number of positive items, O-C = obsessive compulsiveness, P-A = phobic anxiety, P-I = paranoid ideation, SCL-90-R = Symptom Check List-90-R, SD = standard deviation.

($P < .001$), and NPI ($P = .01$). They scored significantly lower on subscale I-S.

3.4. Univariate analysis of possible influencing factors of mental health status of participants

Univariate analysis was estimated after participants were stratified by education level, longest continuous time staying underground, average time staying underground per week, and presence/absence of insomnia and other self-reported physical symptoms. Results are recorded in Table 4. All factors, excluding education level, were associated with at least 1 aspect of mental health changes. Notably, insomnia, higher temperature, tinnitus, and hearing loss were significantly associated with higher scores of all 9 subscales, while fatigue easily were significantly associated with higher scores of all subscales except for P-A.

Table 4

Univariate analyses of the influencing factors on the SCL-90 scale for the mine workers of CPSG.

	Somatization	O-C	Sensitivity	Depression	Anxiety	Hostility	P-A	P-I	Psychoticism	Total average	Positive items
Insomnia											
No (62)	1.36 ± 0.49	1.34 ± 0.53	1.21 ± 0.34	1.26 ± 0.39	1.23 ± 0.43	1.23 ± 0.46	1.16 ± 0.36	1.2 ± 0.35	1.19 ± 0.34	1.25 ± 0.28	16.37 ± 23.25
Yes (204)	1.83 ± 0.8	1.76 ± 0.80	1.63 ± 0.77	1.69 ± 0.80	1.71 ± 0.81	1.65 ± 0.77	1.50 ± 0.73	1.58 ± 0.75	1.58 ± 0.75	1.69 ± 0.73	36.33 ± 28.58
t	19.5	15.49	17.61	17.28	20.4	16.666	12.46	15.72	16.43	20.62	25.15
P	< .01	< .01	< .01	< .01	< .01	< .01	< .01	< .01	< .01	< .01	< .01
Education											
Junior middle school or lower (122)	1.67 ± 0.74	1.61 ± 0.80	1.46 ± 0.73	1.56 ± 0.79	1.53 ± 0.43	1.51 ± 0.80	1.43 ± 0.66	1.45 ± 0.73	1.45 ± 0.73	1.54 ± 0.72	26.43 ± 26.92
Senior middle school or higher (144)	1.81 ± 0.81	1.77 ± 0.76	1.62 ± 0.73	1.68 ± 0.80	1.71 ± 0.81	1.61 ± 0.72	1.57 ± 0.72	1.57 ± 0.71	1.56 ± 0.71	1.67 ± 0.71	35.95 ± 30.06
t	2.00	2.68	2.92	1.18	2.14	1.07	1.75	2.52	1.50	1.86	6.57
P	.15	.11	.09	.28	.15	.30	.19	.11	.22	.17	.01
Longest continuous time staying in DUG, h/d											
≤8 (139)	1.65 ± 0.77	1.62 ± 0.76	1.48 ± 0.67	1.50 ± 0.65	1.55 ± 0.74	1.51 ± 0.71	1.41 ± 0.68	1.45 ± 0.63	1.44 ± 0.64	1.53 ± 0.66	28.83 ± 28.83
>8 (127)	1.82 ± 0.75	1.72 ± 0.76	1.59 ± 0.77	1.67 ± 0.80	1.67 ± 0.8	1.61 ± 0.76	1.43 ± 0.70	1.54 ± 0.72	1.56 ± 0.75	1.67 ± 0.74	35.25 ± 28.73
t	3.35	1.34	1.7	5.48	1.68	1.05	0.12	1	1.97	2.79	3.32
P	.07	.25	.19	.02	.2	.31	.73	.33	.16	.10	.07
Average time of a week staying in DUG, h/wk											
≤40 (128)	1.67 ± 0.75	1.62 ± 0.75	1.50 ± 072	1.57 ± 0.76	1.57 ± 0.74	1.52 ± 0.71	1.40 ± 0.65	1.45 ± 0.65	1.46 ± 0.67	1.56 ± 0.69	30.73 ± 29.15
>40 (138)	1.98 ± 0.79	1.89 ± 0.76	1.70 ± 0.71	1.71 ± 0.72	1.74 ± 0.87	1.71 ± 0.82	1.49 ± 0.76	1.69 ± 0.74	1.66 ± 0.80	1.76 ± 0.71	36.22 ± 26.03
t	0.18	0.54	2.00	1.75	4.39	2.65	9.56	3.50	5.42	1.80	3.91
p	0.68	0.46	0.16	0.19	0.04	0.11	0.02	0.06	0.02	0.18	0.05
Dim lighting											
No (144)	1.61 ± 0.72	1.60 ± 0.80	1.48 ± 0.72	1.53 ± 0.77	1.55 ± 0.77	1.47 ± 0.69	1.40 ± 0.71	1.44 ± 0.71	1.45 ± 0.70	1.52 ± 0.72	27.90 ± 29.83
Yes (122)	1.85 ± 0.73	1.75 ± 0.71	1.60 ± 0.70	1.66 ± 0.73	1.66 ± 0.76	1.66 ± 0.77	1.44 ± 0.63	1.55 ± 0.63	1.55 ± 0.63	1.67 ± 0.67	36.14 ± 26.65
t	6.33	2.77	1.94	2.10	1.42	4.47	0.31	2.10	1.54	3.13	5.56
p	0.01	0.10	0.17	0.15	0.23	0.03	0.58	0.15	0.22	0.08	0.02
Higher temperature											
No (154)	1.60 ± 0.71	1.50 ± 0.64	1.43 ± 0.68	1.48 ± 0.70	1.50 ± 0.66	1.43 ± 0.65	1.34 ± 0.61	1.39 ± 0.61	1.38 ± 0.59	1.48 ± 0.63	27.90 ± 29.83
Yes (112)	1.89 ± 0.81	1.89 ± 0.83	1.68 ± 0.74	1.75 ± 0.88	1.74 ± 0.88	1.72 ± 0.81	1.52 ± 0.76	1.63 ± 0.73	1.65 ± 0.80	1.75 ± 0.75	27.60 ± 27.40
t	9.70	17.90	8.23	7.81	7.16	10.23	4.59	8.77	9.83	9.93	7.57
P	.02	< .01	< .01	.01	.01	.03	< .01	< .01	< .01	.08	.01
Palpitation											
No (205)	1.65 ± 0.76	1.62 ± 0.77	1.50 ± 0.71	1.53 ± 0.72	1.55 ± 0.77	1.54 ± 0.77	1.38 ± 0.67	1.43 ± 0.62	1.45 ± 0.70	1.54 ± 0.70	27.90 ± 29.83
Yes (61)	1.95 ± 0.73	1.82 ± 0.71	1.64 ± 0.71	1.80 ± 0.80	1.78 ± 0.84	1.60 ± 0.60	1.54 ± 0.68	1.68 ± 0.74	1.64 ± 0.69	1.76 ± 0.67	41.91 ± 31.68
t	7.42	3.33	1.91	6.16	4.19	0.28	2.57	6.48	3.57	4.72	10.43
P	.01	.69	.17	.01	.04	.60	.11	.01	.06	.02	< .01
Breathing difficulties											
No (241)	1.70 ± 0.75	1.64 ± 0.76	1.51 ± 0.69	1.56 ± 0.73	1.57 ± 0.77	1.57 ± 0.75	1.53 ± 0.75	1.40 ± 0.64	1.45 ± 0.62	1.57 ± 0.69	30.58 ± 29.00
Yes (25)	2.01 ± 0.82	1.92 ± 0.75	1.78 ± 0.54	1.87 ± 0.90	1.78 ± 0.84	1.92 ± 0.84	1.75 ± 0.70	1.59 ± 0.90	1.84 ± 0.91	1.86 ± 0.80	42.24 ± 23.11
t	4.05	3.16	3.23	3.84	4.77	2.04	1.86	9.60	7.00	4.29	3.79
P	.05	.08	.07	.05	.03	.16	.17	< .01	< .01	.039	.05
Tinnitus											
No (182)	1.61 ± 0.66	1.54 ± 0.64	1.43 ± 0.59	1.50 ± 0.63	1.50 ± 0.65	1.46 ± 0.62	1.35 ± 0.57	1.39 ± 0.55	1.40 ± 0.56	1.49 ± 0.58	29.61 ± 28.25
Yes (84)	1.96 ± 0.91	1.94 ± 0.91	1.75 ± 0.90	1.80 ± 0.93	1.82 ± 0.95	1.75 ± 0.90	1.55 ± 0.85	1.79 ± 0.84	1.70 ± 0.88	1.81 ± 0.86	36.15 ± 29.19
t	12.20	17.20	11.49	9.49	10.16	9.38	4.97	12.08	11.47	12.45	3.02
P	.01	< .01	.01	.02	.02	< .01	.03	< .01	< .01	< .01	.83
Hearing loss											
No (173)	1.60 ± 0.73	1.56 ± 0.72	1.43 ± 0.64	1.49 ± 0.70	1.48 ± 0.70	1.47 ± 0.71	1.34 ± 0.64	1.39 ± 0.61	1.40 ± 0.67	1.49 ± 0.65	26.53 ± 27.13
Yes (93)	1.95 ± 0.78	1.88 ± 0.80	1.73 ± 0.81	1.78 ± 0.80	1.83 ± 0.83	1.72 ± 0.75	1.57 ± 0.71	1.68 ± 0.74	1.67 ± 0.70	1.80 ± 0.74	41.25 ± 29.12
t	13.37	11.18	11.43	8.65	13.20	7.18	7.11	11.81	9.33	12.42	16.90
P	< .01	< .01	< .01	< .01	< .01	.01	.01	< .01	< .01	< .01	< .01
Fatigue easily											
No (159)	1.62 ± 0.75	1.51 ± 0.68	1.44 ± 0.70	1.47 ± 0.72	1.48 ± 0.70	1.43 ± 0.67	1.38 ± 0.67	1.40 ± 0.64	1.40 ± 0.67	1.49 ± 0.66	27.50 ± 28.32
Yes (107)	1.87 ± 0.76	1.89 ± 0.81	1.66 ± 0.72	1.76 ± 0.77	1.78 ± 0.82	1.74 ± 0.78	1.48 ± 0.67	1.62 ± 0.69	1.62 ± 0.71	1.74 ± 0.70	37.79 ± 28.18
t	6.76	16.85	6.18	9.45	9.94	12.02	1.73	0.52	6.49	9.18	8.50
P	.01	< .01	.02	< .01	< .01	< .01	.19	< .01	.01	< .01	< .01

CPSG = China Pingmei Shenma Group, DUG = deep underground, O-C = obsessive compulsiveness, I-S = interpersonal sensitivity, P-A = phobic anxiety, P-I = paranoid ideation, SCL-90-R = Symptom Check List-90-R.

Table 5

Multivariate analysis of the influencing factors on the SCL-90 scale for the mine workers of CPSG.

	Somatization		O-C		Sensitivity		Depression		Anxiety	
	β	P	β	P	β	P	β	P	β	P
Insomnia (yes)	0.56	<.01	0.51	<.01	0.40	.01	0.54	<.01	0.54	<.01
Longest continuous time staying in DUG, h/d (>8)	0.01	.93	0.03	.83	−0.04	.04	0.10	.50	0.08	.62
Average time of a week staying in underground, h/wk (>40)	0.14	.41	0.04	.05	0.16	.97	0.37	.04	0.41	.02
Moisture	0.29	.02	0.24	.06	0.24	.83	0.18	.22	0.21	.14
Narrow space	−0.65	.23	−0.40	.06	0.18	.21	−0.22	.381	−0.59	.13
Nasal obstruction	0.42	.02	0.22	.05	0.17	.15	−0.39	.08	0.5	.02
Palpitation	0.34	.01	0.33	.01	0.15	.35	0.35	.04	0.31	.05
Fatigue easily (yes)	0.14	.34	0.20	.17	0.17	.27	0.27	1	0.18	.24
Breathing difficulties (yes)	0.18	.13	−0.23	1	0.17	.35	0.14	.58	0.29	.24
Hearing loss (yes)	0.24	.31	0.2	.15	0.24	.08	0.21	.15	0.2	.05

	Hostility		P-A		P-I		Psychoticism		Total average		Positive items	
	β	P	β	P	β	P	β	P	β	P	β	P
Insomnia (yes)	0.62	<.01	0.43	<.01	0.49	<.01	0.49	<.01	0.54	<.01	25.68	<.01
Longest continuous work time in DUG (>8)	−0.16	.26	−0.02	.84	<0	.982	0.52	.7	0.05	.8	−0.9	.87
Average time of a week staying in underground, h/wk (>40)	0.48	.01	0.39	.01	0.38	.02	0.53	<.01	0.34	.03	14.08	.03
Moisture (yes)	0.39	<.01	0.16	.19	0.27	.18	0.26	.05	0.26	.05	6.44	.22
Narrow space (yes)	−0.13	.36	−0.11	.38	−0.06	.62	−0.17	.90	−0.15	.26	−6.25	.23
Nasal obstruction (yes)	−0.38	.08	−0.36	.05	−0.37	.07	0.51	.01	0.43	.03	−15.78	.05
Palpitation (yes)	0.04	.87	0.19	.153	0.18	.24	0.13	.17	0.23	.12	13.06	.03
Fatigue easily (yes)	0.16	.3	0.09	.5	0.23	.11	0.16	.26	0.14	.09	8.38	.14
Hearing loss (yes)	0.159	.26	0.22	.06	0.21	.12	0.18	.15	0.16	2.0	9.72	.06
Breathing difficulties (yes)	0.07	.8	0.10	.63	0.3	.19	0.19	.14	0.14	.10	6.06	.5

CPSG = China Pingmei Shenma Group, DUG = deep underground, O-C = obsessive-compulsiveness, I-S = interpersonal-sensitivity, P-A = phobic anxiety, P-I = paranoid ideation, SCL-90-R = Symptom Check List-90-R.

3.5. Multivariate analysis of possible influencing factors of mental health status of participants

All factors found to be associated with any aspect of the SCL-90-R changes were included in multivariate regression analysis, and the results are summarized in Table 5. Longest continuous time staying in DUG > 8 h/d was a significant predictor of high sensitivity. Average time of a week staying in underground >40 h/wk was a significant predictor of high subscales scores of subscales (except for somatization, O-C, and sensitivity), total average scores, and NPI. Moisture predicted higher somatization and hostility. While nasal obstruction predicted higher somatization, anxiety, psychoticism, and total average scores. Palpitation was a predictor of higher somatization, O-C, depression, and NPI. Presence of insomnia could predict adverse changes of all 9 subscales.

3.6. Environmental factors in the 12th mine in CPSG

Measurements of the environmental factors in the 12th mine of CPSG are shown in Table 6 and Figure 1. Air pressure, relatively humidity, CO_2 concentration, and temperature rose with increased depth, while total gamma radiation dose-rate decreased.

4. Discussion

Extensive exploitation of underground resources results in significant increases in both the number of miners and the

Table 6

The relationship between environmental parameters with the depth underground in 12th mine of CPSG.

Depth, m	CO_2 of concentration, ppm	Relative humidity, %	Temperature, °C	Air pressure, hPa	Total γ radiation dose-rate, μSv/h
0	339.43 ± 40.95	54.014 ± 10.42	20.81 ± 4.75	1005.67 ± 6.37	0.138 ± 0.007
−243.5	355.86 ± 18.10	70.56 ± 11.91	20.96 ± 3.15	1032.9 ± 7.00	0.114 ± 0.024
−300	364.29 ± 12.98	69.542 ± 12.31	21.16 ± 3.02	1041.31 ± 12.90	0.104 ± 0.014
−388	370.14 ± 17.38	68.71 ± 12.12	22.06 ± 3.00	1049.44 ± 11.37	0.112 ± 0.012
−530	378.14 ± 7.9	71.66 ± 8.11	23.94 ± 2.63	1060.71 ± 8.60	0.108 ± 0.001
−535	378.43 ± 10.47	74.79 ± 5.70	24.029 ± 2.81	1070.23 ± 5.45	0.088 ± 0.001
−545	378.43 ± 8.14	78.77 ± 6.63	24.39 ± 2.47	1087.4 ± 9.03	0.088 ± 0.012
−655	378.86 ± 15.42	80.97 ± 4.67	24.73 ± 2.22	1099.06 ± 12.43	0.082 ± 0.010
−765	381.71 ± 14.76	82.64 ± 3.10	25.11 ± 2.07	1100.29 ± 13.86	0.082 ± 0.004
−845	386.86 ± 8.19	80.76 ± 5.54	25.81 ± 1.98	1107.16 ± 8.24	0.086 ± 0.022
−885	424.00 ± 37.39	79.6 ± 3.90	26.67 ± 1.97	1109.11 ± 9.05	0.08 ± 0.006
−905	487.29 ± 59.3	83.51 ± 3.16	28.34 ± 1.53	1108.23 ± 8.21	0.068 ± 0.012
−932	481.57 ± 42.48	80.47 ± 1.07	29.63 ± 1.73	1107.00 ± 7.79	0.072 ± 0.004

CPSG = China Pingmei Shenma Group.

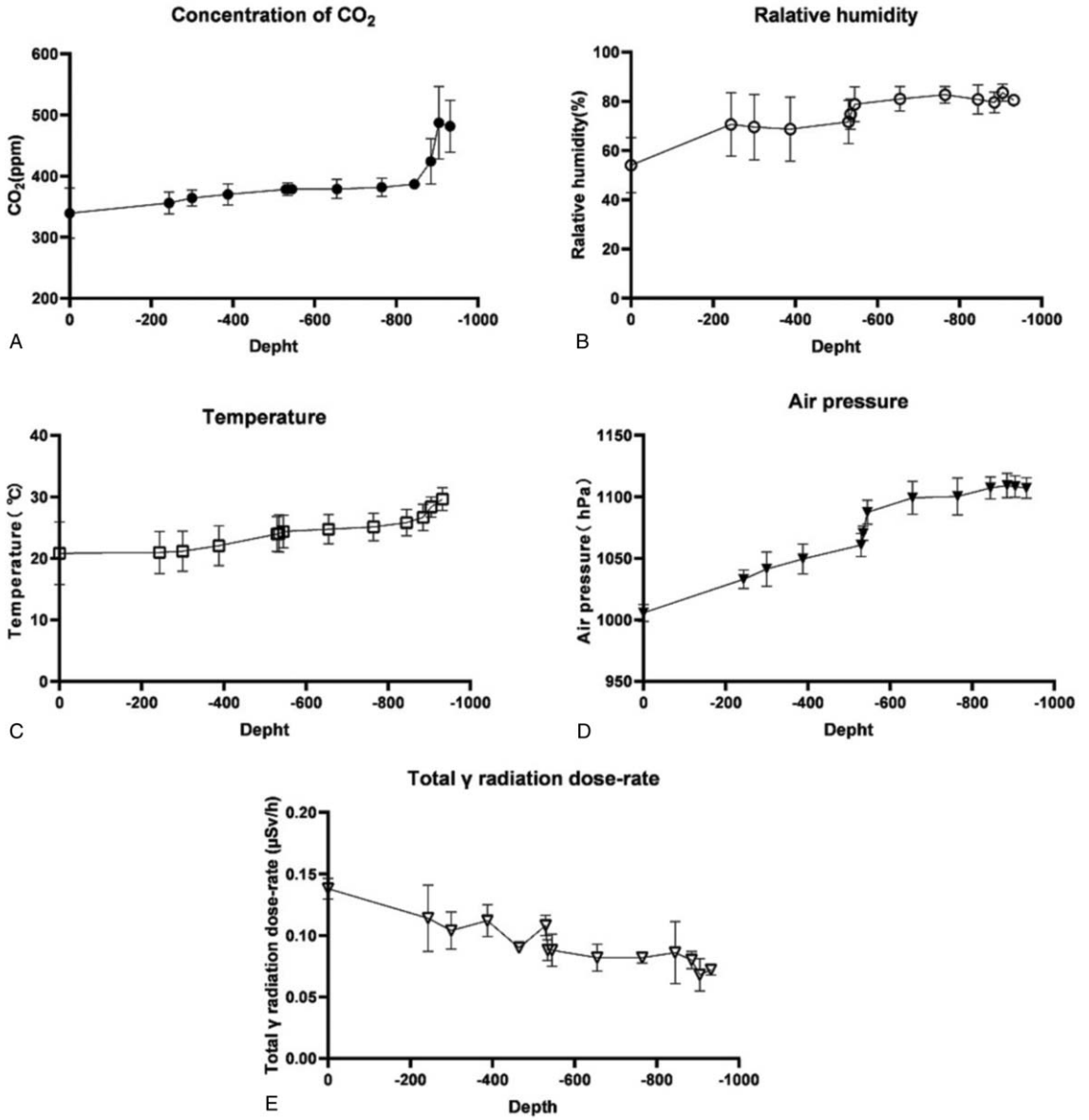

Figure 1. The relationship between environmental parameters (concentration of CO_2, relative humidity, air pressure, temperature, and total dose rate of gamma radiation) and the depth underground in 12th mine of China Pingmei Shenma Group. (A) The concentration of CO_2 increased with the increasing depth below ground. (B) Relative humidity increased with the increasing depth below ground. (C) Temperature increased with the increasing depth below ground. (D) Air pressure increased with the increasing depth below ground. (F) Total gamma radiation dose-rate decreased with increasing depth below ground.

working depth of the underground environment. However, physical and mental health problems are reported by workers in mines.[4,6,7] Physical and mental status may be compromised due to lengthy shifts in deep mines.[4–6,9] Here, scores on most SCL-90-R subscales were elevated compared to Chinese norms, indicating potential psychologic problems. Participants also reported substantial physical symptoms and disliked common features of the deep mine environment that may compromise health.

According to our study analysis, the score of SCL-90-R subscales (somatization, anxiety, P-A, psychoticism, and P-I) revealed a significant uptrend among DUG workers while subscale I-S decreased. These differences suggest that DUG workers are more likely to develop related mental health problems, although the elevated SCL-90-R scores were not confirmed by medical diagnosis. The elevated mental health symptoms probably reflect the objectively and subjectively challenging DUG physical environment. We considered the reason that those consequences were partly resulted from unpredictability concerns of the dynamic environment leading to a continuous presence in risk conditions, particularly when working in thousands depth underground.[7]

The 3 most common uncomfortable symptoms were tiring easily, hearing loss of variable severity, and tinnitus, all reported by at least one-third of the sample. Furthermore, insomnia, which was primarily manifested as trouble in falling asleep and dreams, was also reported. These findings were similar to our investigation in a deep gold mine in China[12] and Joaquim's research,[6]

but different to Küller's findings.[15] Univariate analyses suggested that the 3 most prevalent self-reported physical symptoms were related to worsened SCL-90-R subscales scores and multivariant analysis referred that the physical disorders investigated were associated with worsened SCL-90-R scores. In addition, our findings suggest that physical issues may be responsible for mental health worsening, because somatization scores in SCL-90-R scale were notably higher in DUG workers, suggesting that these physical symptoms may be the reason rather than consequence of abnormal mental health status. Somatization scores may be important in assessing mental health in DUG population.

To confirm the potential factors affecting the health of miners, we measured the environmental parameters of the 12th mine of CPSG. Besides the temperature, air pressure, and relative humidity, which were same as previous measurement in CJEM,[12] CO_2 concentration rose gradually with increasing depth underground. The total dose rate of gamma radiation decreased with increased depth. Except for the change of radiation and concentration of CO_2; the temperature, air pressure, and relative humidity were easily to be perceived. Similar to rock temperature increasing 1°C every 100 m in depth,[7] the temperature of aisle in the 12th mine of CPSG increased from 20.81 ± 4.75°C at 0 m to 29.63 ± 1.73°C at −932 m. Meanwhile, the relative humidity rose from $54.01 \pm 10.42\%$ to $80.47 \pm 1.07\%$. Although the relative humidity in CPSG was lower than CJEM at the corresponding depth, when the depth was 530 m, it still exceeded the upper limit of 70% that is recommended to avoid thermal discomfort.[16] Heat and humidity both are significant risks in underground mines.[7] Here, 74.86% respondents reported moisture, and 33.52% reported heat when they worked underground. Additionally, increased CO_2 concentration and air pressure in deep mines might make matters worse. Aural discomfort, myalgia, and the other physical symptoms recorded here are probably due in part to increased atmospheric pressure. However, extreme humidity and heat will also play a part and all three are likely to affect sleep quality.

One of the strengths of this study is that it recorded both self-reported adverse effects and objective measures of the physical environment. Previous studies have shown changed mental health scores in underground miners, but only one addressed improving mental health, namely depression,[11] while another found that in some cases feelings such as a sense of being trapped could adversely influence mental health status.[17] With the present data on the objective physical environment, as well as aspects of the physical environment that subjects disliked, it is possible to suggest ways of improving DUG conditions. In the 1st instance, enhanced ventilation and lighting to provide dryer air, brighter vision, and more adaptive temperatures, may help to reduce physical discomfort. Measures and guidance to improve sleep quality may also be important and these would be facilitated by further research to understand how the challenging DUG environment affects sleep once the underground shift is over. Another recommendation is routine screening of miners for mental health issues, perhaps using the SCL-90-R and particularly focusing on anxiety and somatization. Introducing plants to a windowless underground space may also improve task performance better than other decorations.[4]

This study had its own limitations. There were correlations between physical symptoms and adverse mental health status, and then we hypothesized that uncomfortable physical performance might result in abnormal mental health changes, but actual causal relationships among these factors were not finally determined. Further research to establish causal relationships is required, possibly some form of longitudinal study. Additionally, there is a need to investigate sleep and shift working more carefully.

5. Conclusion

This appears to be the 1st study examining reported physical and mental health symptoms in a large sample of DUG miners, along with measurement of relevant environmental factors. Physical and mental health were related to each other and plausibly caused by the extreme physical environment DUG. There is a need to introduce measures to reduce these physical stressors as much as possible, for example, by enhancing ventilation and lighting and there is also a need for further research to establish the causal links between environment, physical, and mental health symptoms.

Acknowledgments

The authors sincerely appreciate Mr Zhixu Dai and his colleagues at CPSG in China, for their valuable inputs in this study and data collection. They also thank Prof. Tao Li of the Psychiatric Laboratory and Department of Psychiatry, West China Hospital, Sichuan University for compiling the questionnaire with her assistance. The authors are grateful to Mr Zhiliang Wu and his colleagues at CJEM give guidance to study the environmental parameters of DUG. They also thank Miss Min Peng, Mr Xu Zhang, Guiming Fu, and Chaoting Han for kindly helping record the study data.

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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 HP, Liu JF, Gao MZ, et al. The research advancement and conception of the deep-underground medicine [in Chinese]. Sichuan Da Xue Xue Bao Yi Xue Ban 2018;49:163–8.
[3] Liu J, Ma T, Liu Y, et al. History, advancements, and perspective of biological research in deep-underground laboratories: a brief review. Environ Int 2018;120:207–14.
[4] Soh C-K, Christopoulos G, Roberts A, et al. Human-centered development of underground work spaces. Proc Eng 2016;165:242–50.
[5] Han L, Li Y, Yan W, et al. Quality of life and influencing factors of coal miners in Xuzhou, China. J Thorac Dis 2018;10:835–44.
[6] Joaquim AC, Lopes M, Stangherlin L, et al. Mental health in underground coal miners. Arch Environ Occup Health 2018;73:334–43.

[7] 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.
[8] Liu L, Xu X, Wu H, et al. Associations of psychological capital, demographic and occupational factors with cigarette smoking among Chinese underground coal miners. BMC Public Health 2015;15:20.
[9] Liu L, Wang L, Chen J. Prevalence and associated factors of depressive symptoms among Chinese underground coal miners. Biomed Res Int 2014;2014:987305.
[10] Salas ML, Quezada S, Basagoitia A, et al. Working conditions, workplace violence, and psychological distress in andean miners: a cross-sectional study across three countries. Ann Glob Health 2015;81:465–74.
[11] Liu L, Wen F, Xu X, et al. Effective resources for improving mental health among Chinese underground coal miners: perceived organizational support and psychological capital. J Occup Health 2015;57:58–68.
[12] Liu Jifeng , Liu Yilin , Ma Tengfei , et al. Subjective perceptions and psychological distress associated with the deep underground: a cross-sectional study in a deep gold mine in China. Medicine 2019;98:e15571.
[13] Wang ZY. Symptom Checklist (SCL-90). Shanghai Psychiatry 1984;2:68–70.
[14] 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: Johns Hopkins University School of Medicine; 1977.
[15] Küller R, Wetterberg L. The subterranean work environment: impact on well-being and health. Environ Int 1996;22:33–52.
[16] Fan X, Liu W, Wargocki P. Physiological and psychological reactions of sub-tropically acclimatized subjects exposed to different indoor temperatures at a relative humidity of 70. Indoor Air 2019;29:215–30.
[17] Nie B, Huang X, Sun X, et al. Experimental study on physiological changes of people trapped in coal mine accidents. Safety Sci 2016;88:33–43.