Paradigm Academic Press
Innovation in Science and Technology
ISSN 2788-7030
OCT. 2022 VOL.1 NO.3

The Work Ability of Hydropower Plant Employees in Altitude Conditions of 650 m to 4100 m in China

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doi: 10.56397/IST.2022.10.06

Abstract

Objectives: People exposed to a high-altitude environment show impaired work ability. However, the relationships between the work ability of hydropower plant employees at different altitudes and various influencing factors have not yet been studied. This study focuses on the distribution and factors influencing of work ability in hydropower plant employees working at altitudes of 650–4100 m and explores measures to improve their work ability. ***Methods:*** We randomly selected 374 employees from 12 hydropower plants at different altitudes to carry out cross-sectional research, using a work ability index (WAI) and anxiety self-assessment scale (SAS) to collect information, and then performed an analysis using hypothesis testing, correlation, and multiple linear regression analysis. ***Results:*** The results showed that there is a significant difference in the WAI value of different altitude groups ($p < 0.001$), which decreases by 3.23% on average per thousand m the altitude increases ($p < 0.001$). The main relevant factors include the level of anxiety ($p < 0.001$), the nature of the work ($p = 0.022$), vacation time ($p = 0.004$), and diet ($p = 0.037$). The work ability of hydropower plant employees above 1000 m is lower (WAI < 37) than others. Employees with higher education, 30–40 years old, with high-altitude work experience, and nonsmoking and nondrinking have relatively higher WAI values in each group comparison. ***Conclusions:*** These findings help to formulate practical intervention plans and raise the work ability at different altitudes, especially in high-altitude hydropower plants. In this way, we can help reduce the risk of early retirement.

Keywords: work ability, hydropower plants, different altitudes, WAI, cross-sectional research

1. Introduction

The issue of global warming has promoted the development of renewable energy sources. According to the 2019 Hydropower Status Report from the International Hydropower Association (IHA) (Louis Scorza, Bill Girling & Cristina Díez Santos., 2019), by the end of 2018, renewable energy installed capacity accounted for 25.6% of global energy use, of which hydropower contributed 62.1%. Of the 1292 GW hydropower installations around the world, about 301 GW is distributed in areas higher than 1000 m. China already owns 352 GW hydropower installations, and there are 59.3 GW (69 hydropower plants) distributed above an altitude of 1000 m. In the next 20–30 years, similar hydropower plants with a capacity of about 162 GW (anther 109 hydropower plants) will be put into production, of which 27.6 GW (about 50 hydropower plants) are at an altitude higher than 3000 m. Meanwhile, more and more employees work in hydropower plants. The main tasks of hydropower plant employees include real-time equipment monitoring, equipment inspection, testing, emergency response, equipment operation (start or stop, switch on or off, parameter settings, etc.). The work requires high precision and involves stress and long-term shift work, which can bring on sleep disorders and problems with attention, memory, etc. (Tahghighi, M., Rees, C. S., Brown, J. A., Breen, L. J. & Hegney, D., 2017; Rouch, I., Wild, P., Ansiau, D. & Marquie, J. C., 2005). High-altitude hydropower plant employees also have to withstand the physical and psychological effects of the high-altitude environment.

Work ability is defined as employees having the mental and physical capacity to perform their work (de Vries, H. J., Reneman, M. F., Groothoff, J. W., Geertzen, J. H. & Brouwer, S., 2013), which depends on the perception of their needs and their ability to deal with them during work (Kettunen, O., Vuorimaa, T. & Vasankari, T., 2014). It describes the balance between work needs and a person's functional capabilities (such as physiological conditions, psychological status, individual ability, values, etc.) (Feldt, T., Hyvönen, K., Mäkikangas, A., Kinnunen, U. & Kokko, K., 2009). Many studies have found that the factors influencing work ability involve work environment, work time, physical exercise, sleep, musculoskeletal ability, work load, age, weight, BMI, marital status, education level, work requirements, work experience, social support, the job role, etc. (Kettunen, O., Vuorimaa, T., Vasankari, T., 2014; Rostamabadi, A., Zamanian, Z., Sedaghat, Z., 2017; A Mazloumi, A Rostamabadi, JN Saraji & et al., 2012). However, these factors do not affect people equally (Kettunen, O., Vuorimaa, T. & Vasankari, T., 2014), and in some studies certain of them prove irrelevant (A Mazloumi, A Rostamabadi, JN Saraji & et al., 2012; Tan, C. C., 1991). Employees of high-altitude hydropower plants may suffer from altitude sickness, hearing impairment, dermatitis, and other chronic diseases when they are exposed to low oxygen, low air pressure, dry air, and strong ultraviolet light (Sorensen, L. E., Pekkonen, M. M., Mannikko, K. H., Louhevaara, V. A., Smolander, J. & Alen, M. J., 2008). Heavy physical work and poor working postures during inspection, maintenance, and emergency treatment (e.g., lifting, transport, standing for a long time) may lead to the development of disabling injuries or musculoskeletal disorders (Sezgin D & Esin M N., 2014). Tasks that involve significant stress include early warning analysis and troubleshooting, as well as unpredictable events such as power dispatching and flood peak response. All these situations require employees to make decisions under pressure, which poses a heavy mental burden (Sorensen, L. E., Pekkonen, M. M., Mannikko, K. H., Louhevaara, V. A., Smolander, J. & Alen, M. J., 2008; Bresic, J., Knezevic, B., Milosevic, M., Tomljanovic, T., Golubic, R. & Mustajbegovic, J., 2007). In addition, cognitive impairment can occur after exposure to a high-altitude environment, with the decreased performance mainly manifested in terms of vision, hearing, color discrimination, calculation ability, and fitness. Research on changes in the brain function of soldiers who spent three days at a high altitude showed that auditory response and attention decreased by 14.9% and 11.2%, respectively, compared with on the plains (Jiang, C. H., Liu, F. Y., Cui, J. H., Wang, H. Y. & Liang, G., 2009). Over time, hearing, stability, and other aspects of health will recover, but color discrimination, attention, and short-term memory may be permanently damaged (Roach, E. B., Bleiberg, J., Lathan, C. E., Wolpert, L., Tsao, J. W. & Roach, R. C., 2014; Kryskow, M. A., Beidleman, B. A., Fulco, C. S. & Muza, S. R., 2013; Nation, D. A., Bondi, M. W., Gayles, E. & Delis, D. C., 2017). Higher physical strength and psychological strength may be needed to cope with the special working environment and work requirements. It is thus necessary to study the work ability distribution of hydropower plant employees at different altitudes and the main factors affecting work ability, and to explore organizational intervention measures to reduce the risk of employee disability or early retirement.

2. Methods

2.1 Research Object

We randomly selected 374 employees from 12 hydropower plants (Zangmu, Guoduo, Duobu, Pondo, Batang, Changheba, Nuozhadu, Qiaoqi, Minzhi, Baoxing, Yucheng, and Taipingyi) 650–4100 m above sea level. The inclusion criteria were 20–60 years old, healthy, no plateau contraindications, and no permanent drugs. Informed notification and consent forms were signed before the study was carried out.

2.2 Methods

This study is a cross-sectional study. The data from employees of hydropower plants at different altitudes were mainly collected via paper questionnaires such as the work ability index (WAI) questionnaire and anxiety self-assessment scale (SAS). After the questionnaire was collected, a database was established and the data were analyzed.

2.3 Questionnaire

(1) Demographic characteristics statistical table: 20+ points of key information such as name, age, gender, ethnicity, marital status, height, weight, work unit, work location and altitude, family situation, job position, years of work experience, years working at high altitude, education level, smoking status, drinking status, eating habits, physical exercise, vacation pattern, vacation return status, etc.

(2) Work ability index (WAI) questionnaire: This table was developed by the Finnish National Institute of

Occupational Hygiene and has been translated into more than 30 languages. It is considered reliable (Ilmarinen, J., 2019) and has been used in many countries as an occupational health tool (La ji, M. A., Zhou, T., Jin, T. Y., Shen, G. Z., Xi peng, J. I., Zhang, Q. Z., Wang, Y. Q. & Cao, S. H., 2000; Olatunji, B. O., Deacon, B. J., Abramowitz, J. S. & Tolin, D. F., 2006; Ge, H., Sun, X., Liu, J. & Zhang, C., 2018). The main items are seven components: sense of accomplishment, work requirements, physical condition, work quality, absence due to illness, ability prediction, and psychological resources; the cumulative score is the WAI. The WAI ranges from 7 to 49 points. The higher the score, the better the work ability: 7–27 points is poor, 28–36 points is medium, 37–43 points is good, and 44–49 points is excellent (Ng, J. Y. K. & Chan, A. H. S., 2018).

(3) Anxiety self-assessment scale (SAS): The scale contains 20 items, each of which is rated on a four-level scale. There are 15 items described as negative words and scored in the order of 1–4; the remaining five items are rated as positive word descriptions, in descending order of 4–1 points (Ng, J. Y. K. & Chan, A. H. S., 2018). All entries total 20–80 points. According to the Chinese norm, the score is multiplied by 1.25 and rounded to the nearest whole number to get the standard score. The standard cutoff value is 50 points; 50–59 is mild anxiety, 60–69 is moderate anxiety, and 70 points or more is severe anxiety.

2.4 Statistical Analysis

Statistical analysis was performed using SPSS version 26 software (IBM Corp., Armonk, NY, USA). Quantitative variables are expressed as mean ± standard deviation (M ± SD), and qualitative variables are expressed as a frequency and percentage. The statistical difference between different altitude groups was assessed using a chi-square test according to the data type and distribution (percentage composition data) or a rank sum test (WAI value or grade data). The chi-square trend test is used for the change trend analysis. Person-related analysis is used for data such as age, working altitude, and working years, and data such as gender and marital status are used in the Spearman correlation analysis. The variables obtained from the correlation analysis are included in the multivariate model, and multiple linear regression methods are used to determine the relevant factors of the WAI score. All p values below 0.05 are considered statistically significant.

3. Results

3.1 Work Ability of Different Research Subjects at Different Altitudes

A total of 374 employees (30.08 ± 6.04 years old; 86.4% males) of hydropower plants at different altitudes agreed to participate in this study. The stratification of the research was based on the altitude of the hydropower plant where the research subject located, namely <1000 m, 1000–2000 m, 2000–3000 m, and ≧3000 m. Table 1 lists the sociodemographic characteristics of the research subjects, with $p > 0.05$ in each group.

Table 1. Sociodemographic data, stratified by altitude.

Characteristic Parameters	<1000 m		1000–2000 m		2000–3000 m		≧3000 m		χ^2	p-value
	n = 113	%	n = 96	%	n = 71	%	n = 104	%		
gender									0.761	0.859
male	96	84.96	75	87.21	63	88.73	89	85.56		
female	17	15.04	11	12.79	8	11.27	15	14.42		
marital status									4.083	0.253
unmarried	42	37.17	40	46.51	24	33.80	43	42.35		
married	71	62.83	46	53.49	47	66.20	61	57.65		
age									5.464	0.486
<30	62	54.87	57	66.28	40	57.14	62	60.19		
30–40	40	35.40	26	30.23	25	35.71	34	33.01		
>40	11	9.73	3	3.49	5	7.14	7	6.80		
BMI									11.832	0.67
<24	66	58.93	58	67.44	46	64.79	75	72.82		
24–28	40	35.71	24	27.91	21	29.58	22	21.36		
>28	6	5.36	4	4.65	4	5.63	6	5.83		
education level									10.147	0.119
college and below	10	8.85	9	10.59	12	16.90	17	14.56		

undergraduate	88	77.88	73	85.88	55	77.46	81	79.61		
postgraduate	15	13.27	3	3.53	4	5.64	6	5.83		
working years									15.279	0.084
<5	49	43.36	50	58.14	31	44.29	49	47.12		
5–10	46	40.71	26	30.23	30	42.86	48	46.15		
10–15	12	10.62	9	10.47	5	7.14	4	3.85		
>15	6	5.31	1	1.16	4	5.71	3	2.88		
smoking									4.190	0.242
no	71	62.83	52	60.47	34	47.89	61	58.65		
yes	42	37.17	34	39.53	37	52.11	43	41.35		
drinking status									2.168	0.538
no	33	29.20	33	38.37	26	36.62	35	33.65		
yes	80	70.80	53	61.63	45	63.38	69	66.35		

A Pearson chi-square test is used.

Table 2 considers all of the different altitude conditions. Different groups including male, female, married, <30 years old, BMI <24 or 24–28, undergraduate education, work <5 years or 5–10 years, smoking, nonsmoking, drinking, and nondrinking have differences in WAI ($p < 0.01$). In terms of the mean (M), the WAI of males is higher than that of females, the WAI of unmarried is higher than that of married, the WAI of 30-year-olds is higher than those of <30 and 40-year-olds, the WAI of the group with BMI >28 is higher than that with <24 and 24–28, the WAI of postgraduates is higher than that of undergraduates and below, the WAI of working <5 years is higher than those of longer working spans, the WAI of nonsmoking is higher than that of smoking, and the WAI of nondrinking is higher than that of drinking.

In terms of the average work ability of each altitude group, the majority of WAI in the group below 1000 m is 37, and the overall working capacity is good. The overall WAI of the above 1000 m altitude group is less than 37, and the working capacity is medium. However, what is worth noting is that WAI is above 37 in the 2000–3000 m and ≧ 3000 m groups for females, the working period of 10–15 years, BMI ≧ 28, and graduates with academic qualifications, and the work ability level is good.

Table 2. Work ability index (WAI) of the research object, the average of each altitude group, the average of each group, and a comparison.

Characteristic Parameters	WAI				mean value	F	*p*-value
	<1000 m	1000–2000 m	2000–3000 m	≧3000 m			
gender							
male	38.41 ± 4.70	36.15 ± 5.16	35.06 ± 5.47	34.87 ± 5.24	36.26 ± 5.3	9.033	**0.000**
female	37.47 ± 3.37	34.23 ± 6.46	38.31 ± 6.12	33.40 ± 4.48	35.71 ± 5.2	2.897	**0.045**
marital status							
unmarried	38.39 ± 5.05	36.16 ± 4.93	35.54 ± 5.31	35.79 ± 5.22	36.58 ± 5.19	2.524	0.06
married	38.20 ± 4.22	35.58 ± 5.72	35.36 ± 5.79	33.86 ± 4.94	35.89 ± 5.32	8.099	**0.000**
age							
<30	38.65 ± 4.20	35.67 ± 5.25	35.44 ± 5.47	34.56 ± 5.42	36.12 ± 5.3	7.803	**0.000**
30–40	38.25 ± 4.68	36.55 ± 5.66	36.58 ± 5.02	35.13 ± 4.74	36.72 ± 5.07	2.424	0.069
>40	36.22 ± 5.55	34.83 ± 5.62	29.60 ± 7.30	33.29 ± 5.23	34.0 ± 6.02	1.538	0.233
BMI							
<24	38.77 ± 4.60	36.22 ± 5.41	36.33 ± 5.36	34.34 ± 4.98	36.36 ± 5.32	8.895	**0.000**
24–28	37.86 ± 4.36	35.35 ± 5.55	32.95 ± 5.47	34.90 ± 5.68	35.83 ± 5.34	4.223	**0.007**
>28	35.17 ± 4.32	34.63 ± 3.12	38.00 ± 6.00	37.33 ± 5.44	36.5 ± 4.67	0.354	0.787

education level							
college and below	36.45 ± 4.85	33.17 ± 6.42	35.15 ± 5.74	34.60 ± 5.49	35.49 ± 5.77	0.524	0.668
undergraduate	38.56 ± 4.50	36.12 ± 5.26	34.84 ± 4.94	34.20 ± 4.86	36.36 ± 5.16	13.304	**0.000**
postgraduate	37.80 ± 4.46	37.17 ± 1.61	41.88 ± 5.01	40.17 ± 4.79	37.21 ± 4.77	1.241	0.316
working years							
<5	39.47 ± 4.12	35.10 ± 5.69	37.97 ± 5.94	35.28 ± 5.15	36.82 ± 5.52	7.880	**0.000**
5–10	37.43 ± 4.66	37.31 ± 4.81	32.67 ± 3.60	34.23 ± 5.29	35.43 ± 5.07	8.613	**0.000**
10–15	36.75 ± 5.46	37.00 ± 4.05	37.10 ± 7.70	32.88 ± 4.97	36.37 ± 5.34	0.639	0.597
>15	37.92 ± 2.87	30.00 ± 0.00	33.13 ± 3.33	33.63 ± 3.01	35.11 ± 3.79	3.386	0.062
smoking status							
no	38.50 ± 4.40	36.22 ± 4.58	35.94 ± 5.53	34.86 ± 5.40	36.54 ± 5.1	6.358	**0.000**
yes	37.88 ± 4.75	35.43 ± 6.38	34.94 ± 5.69	34.37 ± 4.79	35.68 ± 5.51	3.446	**0.018**
drinking status							
no	39.29 ± 4.84	36.11 ± 5.00	36.81 ± 5.70	33.71 ± 4.95	36.42 ± 5.44	6.867	**0.000**
yes	37.85 ± 4.35	35.78 ± 5.59	34.62 ± 5.44	35.14 ± 5.21	36.06 ± 5.21	5.330	**0.001**

Using analysis of variance and LSD tests; $p < 0.05$ is indicated in bold.

3.2 The Distribution of WAI Levels at Different Altitudes

As seen in Table 3, there are differences in work ability levels at different altitudes ($p < 0.05$), and there is a linear correlation between work ability and altitude. The overall work ability is moderate and good, accounting for more than 84.1%. The elevation of mid-level capabilities is increasing.

Table 3. Grade distribution of work ability index (WAI) of employees in hydropower plants at different altitudes.

work	<1000 m		1000–2000 m		2000–3000 m		≧3000 m		chi-square		chi-square trend	
ability	*n* = 113	%	*n* = 86	%	*n* = 71	%	*n* = 104	%	χ^2	*p*-value	value	*p*-value
poor	3	2.7	6	7.0	5	7.0	8	7.7	25.401	**0.03**	20.633	**0.000**
medium	36	31.9	38	44.2	37	52.1	60	57.7				
good	59	52.2	37	43.0	25	35.2	31	29.8				
excellent	15	13.3	5	5.8	4	5.6	5	4.8				

Differences are tested using the Pearson chi-square test, and trend changes are tested using the chi-square trend test, with $p < 0.05$ indicated in bold.

3.3 Comparison of WAI Scores at Different Altitudes

Table 4 shows that the WAI scores of employees of hydropower plants at different altitudes are different, with a downward trend: from (38.27 ± 4.53) to (34.66 ± 5.14), the rate of decline in WAI value is 6.17%, 1.36%, and 2.15% per km. The average rate of decline is 3.23%/km. Among the seven components of WAI, there are no differences in terms of sense of achievement, absence from work due to illness, or psychological resources, but there are differences in these four aspects: work requirements, physical condition, work quality, and ability prediction. A Spearman correlation analysis was performed on the WAI and seven component scores and altitude groupings. We found that WAI (r = –0.273, $p < 0.001$), work requirements (r = –0.166, $p = 0.001$), physical condition (r = –0.148, $p = 0.004$), work quality (r = –0.259, $p < 0.001$), absence due to illness (r = –0.133, $p = 0.010$), ability prediction (r = –0.304, $p < 0.001$), and psychological resources (r = 0.112, $p = 0.030$) are related to altitude. Including WAI, work requirements, physical condition, work quality, absence from work due to illness, and ability prediction, scores overall decrease with altitude; the average decline rates were 0.52%, 3.59%, 6.69%, 3.86, 1.63%, and 7.06%, respectively, the mental resource score increased with elevation, and the average increase rate was 4.13%.

Table 4. WAI score at different altitudes.

WAI	<1000 m n = 113	1000–2000 m n = 86	2000–3000 m n = 71	≧3000 m n = 104	F	p-value	H test	p-value
Total score	38.27 ± 4.53	35.91 ± 5.34	35.42 ± 5.59	34.66 ± 5.14	10.006	**0.000**		
1: sense of accomplishment	7.52 ± 1.35	7.22 ± 1.71	7.52 ± 1.32	7.39 ± 1.42	0.849	0.468		
2: work requirements	7.38 ± 1.50	6.65 ± 1.80	6.70 ± 1.91	6.59 ± 1.89	4.622	**0.003**		
3: physical condition	4.31 ± 2.23	3.79 ± 2.14	3.54 ± 2.12	3.49 ± 2.10	3.175	**0.024**		
4: Work quality	5.65 ± 0.80	5.48 ± 0.98	5.20 ± 1.17	5.02 ± 1.21			25.111	**0.000**
5: absence from work due to illness	4.77 ± 0.65	4.63 ± 0.75	4.59 ± 0.80	4.54 ± 0.87			7.673	0.053
6: Ability prediction	6.50 ± 1.20	5.78 ± 1.74	5.48 ± 1.75	5.21 ± 1.87			35.791	**0.000**
7: Psychological resources	2.14 ± 0.78	2.36 ± 0.88	2.39 ± 0.87	2.41 ± 0.90			6.284	0.099

In the WAI total score and the seven subitems, the first four items are homogenous, so the variance analysis is used; the last four items are uneven, so the rank sum (H) test is used, with $p < 0.05$ indicated in bold.

3.4 Anxiety Level of Employees at Different Altitudes

This study evaluates mental health, as represented by anxiety, as shown in Table 5. Anxiety levels varied with altitude (χ^2 = 26.126, P = 0.002): the proportion of severe, moderate, and mild anxiety levels increased from a total of 10.7% to 36.6% with altitude, while the percentage of those with no anxiety symptoms decreased from 89.3% to 63.4% as the altitude increased.

Table 5. Anxiety of workers at hydropower plants at different altitudes.

Anxiety	<1000 m		1000–2000 m		2000–3000 m		≧3000 m		Likelihood ratio		Gamma	
	n = 113	%	n = 86	%	n = 71	%	n = 104	%	χ^2	p-value	value	p-value
None	101	89.3	59	68.6	51	71.8	66	63.4	26.126	**0.002**	0.332	**0.000**
Mild	7	6.2	20	23.2	12	16.9	24	23.1				
Moderate	2	1.8	4	4.7	5	7.1	9	8.7				
severe	3	2.7	3	3.5	3	4.2	5	4.8				

Using likelihood ratio chi-square test and Gamma test, with $p < 0.05$ indicated in bold.

3.5 Analysis of Related Factors of WAI

Through a two-variable correlation analysis, this study explored the correlation between the person's WAI and five continuous variables of age, BMI, workplace altitude, working years at this altitude, and anxiety level, where WAI is significantly correlated with the workplace altitude (r = –0.247, $p < 0.001$) and anxiety level (r = –0.478, $p < 0.001$). At the same time, the work ability level was explored by Spearman correlation with 17 categorical variables: gender, ethnicity, age, marital status, years working at high altitude, work types, work category, working age, education, drinking status, smoking status, hobbies, diet, job position, exercise, vacation pattern, and speed of returning to normal when they come back to work. We found that work ability was significantly correlated with education (r = 0.153, P = 0.003), diet (r = 0.167, p = 0.001), the nature of the job (r = 0.174, p = 0.006), the vacation pattern (r = –0.156, p = 0.003), and the speed of return to normal (r = –0.121, p = 0.028). A total of three negative correlation factors were found, education, diet, and nature of work, and there are four negative correlation factors: anxiety level, workplace altitude, vacation pattern, and speed of return to normal. Due to the different degrees of correlation between the altitude of the work site and the other six factors, we excluded the risk of collinearity by performing a collinearity test and finding a VIF value of less than 5. Multiple linear regression analysis excluded the three variables of altitude, education, and speed of return to normal, so four variables were retained: anxiety level (β = –0.48, $p < 0.001$), vacation pattern (β = –0.177, p = 0.004), diet (β = 0.128, $p = 0.037$), and nature of work (β = 0.143, $p = 0.022$).

4. Discussion

4.1 Work Ability Distribution of Hydropower Plant Employees Under Different Altitudes

The work ability of hydropower plant employees declines with increasing altitude. The higher the altitude, the more obvious the decline. These findings are consistent with existing reports (Qinghai Shi & Jianfeng Fu, 2012): the WAI decreases by about 3.23% with every 1000 m of increasing altitude. It has been found that the maximum work volume decreases by 10% with every 1000 m increase when the altitude is 1500 m in an above-plateau hypoxic environment (Jinjuan Tang & Yang Yang, 2018). At the same time, attention span, attention transferability, short-term memory, complex thinking judgment, thinking flexibility, and other brain functions decline, too (Qiang Ma, Zhiqing Zhang, Xuewei Chen, Bo Cui, Zhaoli Chen, Peibing Li & Lei WU, 2014). The work of hydropower plant employees includes manual work such as daily inspections, equipment inspections, and fault repairs, as well as intellectual tasks such as designing generators, turbines, and other mechanical and electrical systems, data analysis, and program comparisons. Overall ability in terms of solving problems and coping with everyday tasks reflects a comprehensive impact of altitude on hydropower workers' labor capacity and brain function. It is worth noting that the average prevalence (or number) of hydropower plant employees is 69.03% (2.2), 79.07% (2.66), 81.7% (2.85), and 82.7% (3.02), corresponding to the four altitude groups from low to high. The high prevalence of diseases reveals that the work ability of hydropower plant employees decreased, which indicates the possibility of disability or early retirement.

The study found that almost all groups at <1000 m have good work ability (WAI > 37); with every additional 1000 m of elevation, the proportion of "good" and "excellent" ratings declines and the "poor" rating rises, which is similar to existing research conclusions. However, the increase in the proportion of "medium" ratings had an average rate of increase of 8.6%/km, which provides ideas for improving the WAI. Firstly, it is possible to study the reclassification of the types of work at high-altitude hydropower plants and to organize labor in a targeted manner. It may be possible to improve performance and work efficiency by improving matching between employees and jobs. A second strategy is to continuously improve the level of informatization. It is possible to hand over repetitive tasks of hydropower plants such as fault inspection, data collection, and report generation to robotic operations, transforming industry production methods to create new job types to match the capabilities of employees. For instance, Boston Dynamics' Spot robots are used in the Norwegian oil company Aker (Biewener, A. A., 2011; Niquille, S. C., 2019).

4.2 Factors Influencing the Work Ability of Employees of Hydropower Plants at Different Altitudes

Among the seven relevant factors, the following aspects are worth paying more attention to: the vacation patterns of 12 hydropower plants at different altitudes are quite different. The options are two days per week, four days per half-month, nine days per month, 20 days every two months, 30 days per half-year (usually spending weekends at the power plant), 60 days per year (spending weekends at the power plant). The vacation periods are longer for hydropower plants at higher altitudes. Studies have shown that the longer the vacation time, the more time there is to overcome dizziness, headache, chest tightness, nausea, anorexia, drowsiness, and insomnia. The more specific the job requirements are (monitoring, inspection, etc.), the better the work ability. Meanwhile, the better the living conditions and the unit logistics, the better the work ability of employees. The higher the education level, the stronger the cognitive ability and the active adaptability to the environment, and the better the work ability. A better educational background and higher workplace happiness have been proven to improve work efficiency (A Mazloumi, A Rostamabadi, JN Saraji & et al., 2012; Ilmarinen, J., 2019).

Anxiety is a risk factor for work ability (Xing Shu, Yongjian Yang, Deqin Qin, Mei Xiang, Jianghong Man & Hong Wu, 2011), and the close relationship between anxiety and work ability is further confirmed in this study. Employee anxiety is a more serious issue at high-altitude hydropower plants. In the <1000 m group, the proportion of anxious employees is 10.7%. This is 2.4-fold higher than the norm (the anxiety prevalence rate in the domestic population is 4.5%) (Xianfu Chen, Long Ma, Yongjuan Song, Honglian Lu & Xingxiang Qi, 2017). As the altitude increases, the proportion of anxious employees increases. The proportion of anxious employees in the ≧3000 m group is 36.6%, 3.8 times that of road workers (9.6%) (Xianfu Chen, Long Ma, Yongjuan Song, Honglian Lu & Xingxiang Qi, 2017) and 3.2 times that of military employees (11.5%) (Junqing Dong, 2013). The correlation between anxiety and altitude (r = –0.197, $p < 0.001$) is significant: for every additional 1000 m, the average increase rate is 8.63%. Anxiety is more prominent for employees who have worked in high-altitude hydropower plants for a long time and have just started to adapt after coming back from vacation. Anxiety is common after exposure to high-altitude environments, and it is easy to show serious body discomfort (Junqing

Dong, 2013). A diversified diet and moderate physical exercise multiple times a week are conducive to easing the tension of employees and maintaining a good mental state (Tang, X. Z., Xiao, H. Z. & Huang, H. L., 2015), which can reduce the anxiety level of employees at high-altitude hydropower plants. This has also been found in past studies (e.g., (Xing Shu, Yongjian Yang, Deqin Qin, Mei Xiang, Jianghong Man & Hong Wu, 2011)).

In this study, the altitude is undoubtedly an important factor, and is related to 13 of the 22 selected factors, including seven factors that have been confirmed and related to work ability. However, the VIF test excludes the collinearity of this factor. Still, the results of multiple linear regression reveal that altitude is a comprehensive index of influence, involving phenomena such as hypoxia, low air pressure, high radiation, a high temperature difference between day and night, sparse population, a desolate environment, and a location far away from home. All of these factors can affect the balance between human resources and work (Ilmarinen, J., 2009). In future research, the specific indicators should be as clear as possible so that interventions can be more targeted.

4.3 Evaluation of Work Ability of Employees of Hydropower Plants Under Different Altitudes

The factors influencing work ability revealed by this research are similar to those that affect teachers, physicians, nurses, etc. The long-term shift work of hydropower plants includes not only mental work such as scheduling analysis and monitoring failure analysis, but also physical work likes parts and equipment handling, and regular inspections. As manual laborers, male employees tend to have a higher working capacity than females; that there is a lower number of female employees (less than 15%) is reasonable (Ng, J. Y. K. & Chan, A. H. S., 2018), but this phenomenon is not absolute, as our studies have shown that the WAI of female workers is greater than that of males at 2000–3000 m. Hydropower plants are usually located in remote areas; the boring environment and singular nature of the work mean that unmarried employees have no opportunity for other social relationships and no family in the area. This often leads to the work ability of unmarried employees being better than that of married employees. Employees working at high altitude for five years have more enthusiasm and are less troubled by chronic diseases, so they have a higher working capacity than employees of longer employment. Thirty-to 40-year-old employees have rich work experience and higher work capacity than employees of other ages. The work of hydropower plants involves electrical, mechanical, hydraulics, hydrology, and communications knowledge and high educational requirements (Niquille, S. C., 2019), so the work ability of postgraduate staff is higher than that of those educated to undergraduate level or below. In addition, hydropower plant equipment management requires acute concentration and attention, so the work ability of nonsmoking and nondrinking employees tends to be higher. For hydropower plants at an altitude of less than 2000 m, thin employees have a higher work ability, but when the altitude exceeds 2000 m, the work ability of obese employees is higher, different to what has been found before (Ng, J. Y. K., Chan, A. H. S., 2018). Therefore, of hydropower plant recruitment can consider factors such as academic qualifications, work experience, ability to learn, life habits, and other factors.

Compared with some existing industries in China, we found that the WAI value (36.18 ± 5.28) of hydropower plants is lower compared with the coal industry (42.53 ± 5.39), chemical industry (41.32 ± 4.08), petroleum drilling (39.66 ± 4.81), construction (37.14 ± 4.38), meteorology (37.41 ± 6.024), etc. (Yin, Y., Lan, Y. J. & Chen, X. N., 2011, Zhixia Wang, Yaolin Yang, Jinzhen Wang & Enfei Jiang, 2007). The nature of the posts above is similar to hydropower plants, but many hydropower plants are distributed in environments with different altitudes, are more remote, are far away from family and friends, and the working environment is difficult, with monotonous or repetitive work leading to a low work ability. There is a risk of future work ability loss (Harma, M., 2011), so the industry should devote resources to combating this potential loss.

5. Conclusions

The work ability of hydropower plant employees at different altitudes decreases with the increase in altitude, but from the perspective of the performance of medium-level work ability, measures for the subdivision of work types and improvement of informatization are worth exploring. According to the analysis of various influencing factors, improving the working environment of hydropower plants, establishing appropriate vacation patterns, offering good culture and entertainment opportunities, providing a diverse diet, encouraging employees to get physical exercise and strengthen their health awareness, and improving the ability to learn after returning from vacation are interventions that are conducive to improving work ability. Compared with other industries, the work ability of employees in hydropower plants is lower, so industry resources should be devoted to finding solutions.

Fund Project

The authors have no conflicts of interest to declare. This work was supported by the National Key R&D Program of China (grant number 2018YFC1508600) and the Sichuan Youth Science and Technology Innovation Research Team Project (grant number 2020JDTD0006). The funders had no role in planning or conducting the current

study, interpretation of the results and no decision in submitting the paper for publication.

Disclosures

Approval of the research protocol: Design and conduct of the study have been approved by the Medical Ethics Committee of Sichuan University. *Informed consent:* Participants were fully in-formed about the aim and procedure of this study prior to giving consent to participate in this study, and written informed consent was obtained from each participant. Registry and the registration no. of the study/trial: N/A. Animal studies: N/A. Conflict of interest: The authors have no conflicts of interest directly relevant to the content of this article.

Authors' contributions

Jing Yang and Xingguo Yang conceived and designed the study. Jing Yang and Haibo Li participated in the literature review and data collection. Jing Yang and Wen Wei participated in the data cleansing and analysis. Xingguo Yang and Yong Liu conducted the article quality evaluation. All authors have discussed and agreed to publish the manuscript.

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