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Research article

Study on the change of miners' psychological state under different illuminance levels

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ABSTRACT

The poor lighting environment in the underground coal mine is easy to cause the miners to have psychological irritability, which leads to the occurrence of accidents. In order to reduce the incidence of accidents and ensure the personal safety of miners. In this paper, different illumination levels are used as control variables. With the help of cognitive ability tests commonly used in psychology, accuracy(AC), reaction time(RT)and performance indicators(PI) are selected to describe how different illumination levels affect the psychological state of miners. The results show that: (1) In the two selected cognitive ability test tasks, when the illumination level is very low, the AC is not high and the RT is longer. As the illumination increases, the AC in the cognitive test task becomes higher and the RT becomes faster. The optimal value is reached at 200lux–300lux.At this time, the illumination level increases again, the AC value decreases, and the RT value increases. When the illuminance is lower than 200Lux, the results of the two tasks are not the same, but when 200Lux~300Lux, the PI values are larger, and then increase the illuminance, the PI value decreases. (2)The regression analysis of three indicators and illuminance level was carried out, and the binary linear regression equation of different illuminance levels and PI/RT was established to monitor the influence of illuminance on the psychological state of miners. (3) Reasonable control of lighting environment can effectively promote the cognitive ability of miners in the work, and minimize the risk of coal mine accidents.

1. Introduction

In China's three major fossil energy reserves, coal accounts for nearly 70 %. This resource situation makes China's basic energy rely heavily on coal, and coal is still the pillar of China's energy supply [1]. In the past 10 years, although the situation of coal mine safety production in China has improved, the number of accidents and deaths of large and above has shown a downward trend [2,3], coal mine safety is still the focus of our research. 80 % of human information comes from vision [4],the level of environmental illumination not only affects people's physical health, emotional fluctuation and comfort, but also greatly affects the speed of people receiving information and the ability to process information, and affects people's work efficiency.

In many non-coal studies, it is found that when the illumination is too low, people's psychological state is not good, and their

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cognitive work ability will also decrease.Based on cognitive psychology, a lot of research has been done on light from a psychological point of view, light affects people 's psychology through visual and non-visual effects, which in turn affects the work efficiency of indoor staff [5].Illumination can also affect people 's subjective feelings, so that people will have a less pleasant performance [6,7], in turn, it has an impact on the output performance of cognitive tasks [8,9]. Some people think that workplace satisfaction can be changed by controlling indoor environmental illumination [10], and cognitive work ability can be improved [11], and a cognitive psychology work efficiency evaluation model is established [12]. Daily variations in the light environment are important for long-term health [13]. Studies have also found that poor lighting or low illumination can easily cause visual fatigue, affect people's psychological mood and alertness [14–19], and reduce operational reliability [20] and cognitive level [21–23]. Lighting affects people 's attention [24], which in turn affects cognitive output and task execution, light can affect mood-related hormones, which in turn affect people 's mental state [25], and can treat some emotional disorders [26,27].

The analysis of the causes of coal mine accidents shows that the occurrence of many accidents is directly or indirectly related to the dim underground light environment. Researchers have realized that the interaction between light factors and human physiological and psychological factors is the main cause of coal mine accidents [28]. Lighting has become one of the key factors causing casualties in underground mines, improving the lighting environment can reduce casualties in underground mines[29]. On the one hand, the brightness of light will have an impact on the visual environment. The weak light environment affects people 's vision [30], when people accept and use light, the physical properties of light are transformed into psychological perception, and vision can be regarded as a psychological process,on the other hand, safety psychology has a very important relationship with safety production, people are often affected by various psychological factors in the process of production and operation [31,32],these factors will affect people 's psychology and behavior [33,34], thereby affecting the reaction time and operational reliability. If the miner continues to work in the underground environment with poor visual environment for a long time, it will cause anxiety and unsafe behavior of the miners, resulting in the occurrence of operation accidents. The simulation experiment system of coal mine lighting is established to analyze the influence of light environment quality on human psychological comfort. According to this, the underground lighting environment can be improved and the work efficiency can be improved [35].

In summary, indoor illumination has a significant impact on cognitive processing, subjective emotion and ability performance in daily activities, and subjective emotion and ability performance are closely related to cognitive processing. These results prompted us to further think about the relationship between illumination and cognitive processing. Based on previous studies, we boldly speculate that the impact of illumination on cognitive processing is likely to be achieved through psychological mediation. Illumination affects people's psychological state, which in turn affects safety. Many studies have found that light has an effect on people's cognitive mechanism,for example, Chinese scientist Professor Tian Xue and Jin Bao's team of researchers have revealed the effect of early developmental light perception on the advanced cognitive ability of the adult brain,the research results were published in the internationally renowned journal ''Cell'', indicating that light entering the brain affects cognitive ability. As a basic psychological process, memory and judgment are directly related to many complex cognitive activities (such as reasoning, arithmetic, problem solving, etc.). The level of these two abilities will directly affect people 's daily behavior and work performance [36,37]. According to the above assumptions, the author believes that the poor illumination will directly affect people 's psychological state through visual effects,for example, when the illumination of the light environment is dark, it will produce psychological fatigue by affecting people's emotions, affecting people's reaction state and operation accuracy. Based on this, this study is based on cognitive safety psychology, with the help of cognitive ability test, according to the selected cognitive ability test indicators AC, RT, PI, it is concluded that different illumination levels affect the psychological state of miners, leading to unsafe behavior, and establish a regression equation to quantify the impact of different illumination levels on the psychological signals of miners, therefore, it provides a basis for determining the psychological threshold of human accidents, informs the psychological indicators of workers in dangerous areas in advance, and plays a role in preventing accidents. At the same time,it provides a psychological theoretical basis for the necessity of implementing lighting protection measures for underground workers.

This paper is organized as follows. Section 2 introduces the research methods of this paper. Section 3 analyzes the data and obtains the calculation results, Section 4 discusses the results of the study. Section 5 summarizes the conclusions of this study.

2. Methodology

2.1. Participants

Taking into account the physical and working conditions, this experiment selected 30 people from the school's undergraduate safety single enrollment (the school's safety single enrollment is all coal mine enrollment) to avoid the effectiveness of the results caused by the large age gap. Selection requirements.

(1) Aged 23–25 years old (mean age 24.2 years old), in good health, no central nervous system disease, no history of mental illness, some basic physiological indicators ((the resting heart rate is 60–100 beats), blood pressure(the normal range of blood pressure in a quiet state is 90–140 mmHg systolic and 60–90 mmHg diastolic), body temperature(the normal range of axillary body temperature is 36–37°) etc) are in the normal range, before the experiment to carry out health examination to ensure that the visual and auditory are normal and barrier-free (before and during the experiment did not use drugs);
(2) The subjects were guaranteed to take any drugs that may affect the physiological state before or during the test. They did not drink coffee or alcohol drinks within 24 h before the test, and ensured adequate rest for 8 h (according to the Munich time-type

questionnaire, none of them was very late or very early, and they did not travel or stay up late in the month before the start of the experiment). Maintain a regular diet, no abnormal mood fluctuations, and avoid subjective discomfort;

(3) According to the specific conditions of the laboratory, combined with the normal physiological conditions of the human body, the daily test time is set (8:00–11:00,14:00–17:00, each tester is only exposed to the test light during the test, and the rest time is exposed to about 8lux ambient light) ;

(4) The whole experiment process needs to be configured with two experimenters, one is responsible for the test, and the other is responsible for dealing with the unexpected situation of the test process.

2.2. Experimental arrangement and materials

According to the average value of the measured temperature, humidity and other data in the coal mine, and the characteristics of the fully mechanized working face, the simulation laboratory (4 m long, 3.2 m wide) is arranged in a closed or semi-closed state (see Fig. 1). During the test, the laboratory curtain has good shading performance. After pulling up, the ambient illumination is about 8lux, which ensures the uniqueness of the experimental light source and maintains the semi-closed state of the laboratory. The indoor air humidity was controlled at 85 % ± 5 % and the temperature was controlled at $20^{\circ} \pm 2^{\circ}$.

Participants sat at a table, and the light source is ML808 retractable floor lamp and OPEL E27 LED energy-saving bulb (3W,5W,7W,9W,13W,18W, color temperature 6000K).The illuminance meter is shown in Fig. 2. According to the experimental requirements, manually replace the telescopic bracket of the floor lamp or change the number of light bulb tiles to facilitate the change of illuminance. The remaining spectral parameters are measured using the calibrated JETI Specbos 1501 (spectral range 380–780 nm, wavelength resolution 1 nm). The measurement of illumination, spectrally weighted α-opic equivalent solar irradiance (EDI), etc.needs to select a fixed point (dotted circle) in the direction of the subject 's eye line of sight. As shown in Table 1, the experimental light is stable during the experimental stage.

2.3. Experimental equipment

E-prime software is used to assist the experiment. The software is a universal psychological experiment generation system, and the timing accuracy can reach the millisecond level.

According to the illumination environment studied in this paper, different illumination levels will affect the psychology through vision, and then affect the behavior of miners. When choosing cognitive test items, we should not only consider the memory ability and logical thinking ability of the subjects, but also pay attention to the difficulty of the task and the operability of the laboratory. Two test items were selected: Stroop word color interference and Meaningless figure recognition test.

The Stroop test is proposed by the American psychologist John Riddly Stroop [38], which is used to test executive function and cognitive control ability. The phenomenon that color information and word meaning information interfere with each other is the famous Stroop effect [39].Stroop word color interference test, as shown in Fig. 3:This content mainly tests the coordination ability between human visual perception and text response,the test consists of 20 visual signals, each of which is a color word, such as ''red'', whose color can be used in any color (except red). The whole test only includes Stroop word test. Each person looked at two pictures in turn, and one picture was arranged in 10 words in turn, and the subjects were asked to read out the words they saw. In the test process, you need to be quiet, can not be blocked, in order to avoid errors.

The recognition of meaningless graphics belongs to visual memory and spatial image memory [40], which can objectively reflect the changes of visual memory function [41].Meaningless figure recognition test, as shown in Fig. 4:The project mainly tests the instantaneous memory ability. The 10 numbers given in the first digit do not mean any meaning, and there is no correlation between them. The participants completed the memory within 10 s, and then gave any 20 pictures. Among the 10 pictures that have just

Fig. 1. Setting of test environment.

Fig. 2. MS6612 lux meter.

Table 1
Spectrally weighted α-opic equivalent daylight illuminance (EDI) at eye level for each lighting level.

	λ_{max}	(6000K,20lux)	(6000K,100lux)	(6000K,200lux)	(6000K,300lux)	(6000K,500lux)	(6000K,700lux)
Illuminance (lx)		24	106	209	314	528	736
Melanopic	470	18	105	194	280	398	684
S-cone	420	16	98	179	256	320	567
M-scone	540	15	96	168	246	286	498
L-cone	580	22	103	190	298	379	486
Rhodopic	500	13	95	176	280	498	712

Note: The table contains the illuminance, CCT, and α-opic EDI measured at the test position for each illumination level setting. The α-opic (melanopic, rhodopic, S-cone, M-cone and L-cone) EDI in lx were determined using the calculation toolbox developed by CIE [54].

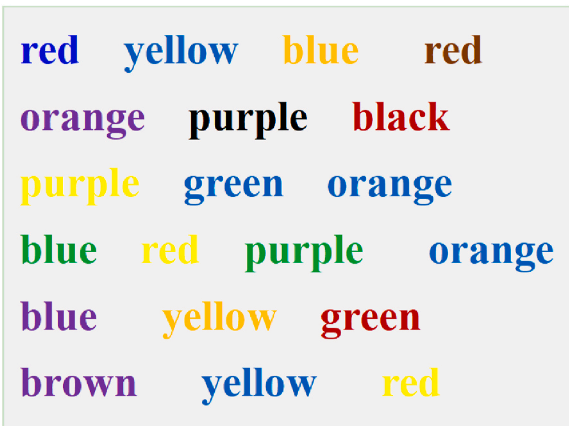

Fig. 3. Stroop word color interference test.

appeared and the other 10 similar interference pictures, the subjects were asked to judge the 10 pictures that have appeared in the 20 pictures, and the subjects were asked to answer "yes" and "no" loudly. The test should be quiet, can not be blocked, so as not to make mistakes.

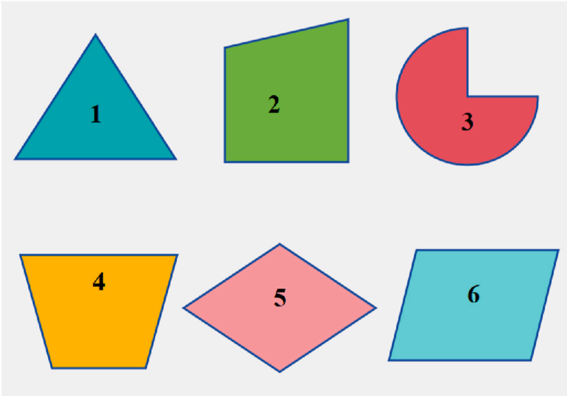

Fig. 4. Meaningless figure recognition test.

2.4. *Experimental design and procedures (see Fig. 5)*

3. Results

3.1. *Data analysis*

Cognitive ability test test data were automatically saved in E-prime 2.0 software, and the data were exported at the end of the test, and the data results were processed with the help of Origin 2018 and Spss 26.0 software.In order to describe the various characteristics of the measurement samples and the overall characteristics they represent, the intrinsic regularity of the data were identified in order to select the methods of result analysis.

(1) Data entry Spss 26.0, in this study, illuminance, AC, RT, PI are four variables, in which attention is paid to set the "value" of variable illuminance as (1.00 = 20lux), (2.00 = 100lux), (3.00 = 200lux), (4.00 = 300lux), (5.00 = 500lux), (6.00 = 700lux).
(2) Multifactor ANOVA: Select Analyze→General Linear Model→Multivariate (Assume that the three sets of data follow a normal distribution).
(3) "Options" settings: Main dialog box settings: send the analyzed variables (AC, RT, PI) into the "Dependent Variable" box→send the grouped variables (illuminance) into the "Fixed Factor(s)" box. Fixed Factor(s)" box; Options" settings: click the Options button, check the "Descriptive statistics" (show statistical description) and "Homogeneity tests" (variance chi-square test)→ Continue→OK; you can get the "Descriptive Statistics" table.
(4) After a multivariate ANOVA has shown that the difference between the overall means of the groups is statistically significant, multiple comparisons of the sample means are performed. Multiple comparisons between means: the main dialog box settings as above, click on the post hoc comparisons→send the"illumination" into the post hoc test box→ in the Equal Variances Assumed (variance chi-squared) box, check the multiple comparisons method:S–N–K, Dunnett→Continue→OK; you can get the "Between-Subjects Effect Tests "and "Multiple Comparisons" tables as shown in Tables 4 and 5.

Descriptive statistics were used to analyze the overall profile of the three indicators AC, RT and PI selected for the two cognitive ability tests under different illumination levels, as shown in Tables 2 and 3, which show the descriptive statistics of the indicators of the Stroop word color interference test and Meaningless figure recognition test respectively under different illumination levels.

3.2. *Trends and regression analyses of AC, RT and PI indicators of the stroop word color interference test*

The original test data of Stroop word color interference test was imported into the software Origin 8.0 and plotted in Fig. 6.

As shown in Fig. 6, for the reaction time (RT) line, the reaction time was 11.5s at the initial illumination of 20lx. As the illumination level gradually increased, the reaction time was prolonged. However, when the illumination level increased to 200lx, the reaction time of the Stroop word color interference test began to shorten, and the reaction time was the shortest at 300lx, and the reaction ability reached the fastest. At this time, the illumination level was increased until 700lx, and the reaction time was rising and did not decrease.

For the accuracy (AC) line, the accuracy rate was 86.9 % at the initial illumination of 20lx. The accuracy rate was the lowest at the illumination level of 100lx, and the illumination level was higher than 100lx. As the illumination level gradually increased, the accuracy rate was also rising. At 300lx, the accuracy rate of the Stroop color interference test was the highest, but at this time, the accuracy rate began to decline.

For the performance indicators (PI) broken line, it reflects the accuracy rate per unit time. When the illumination level is too low to

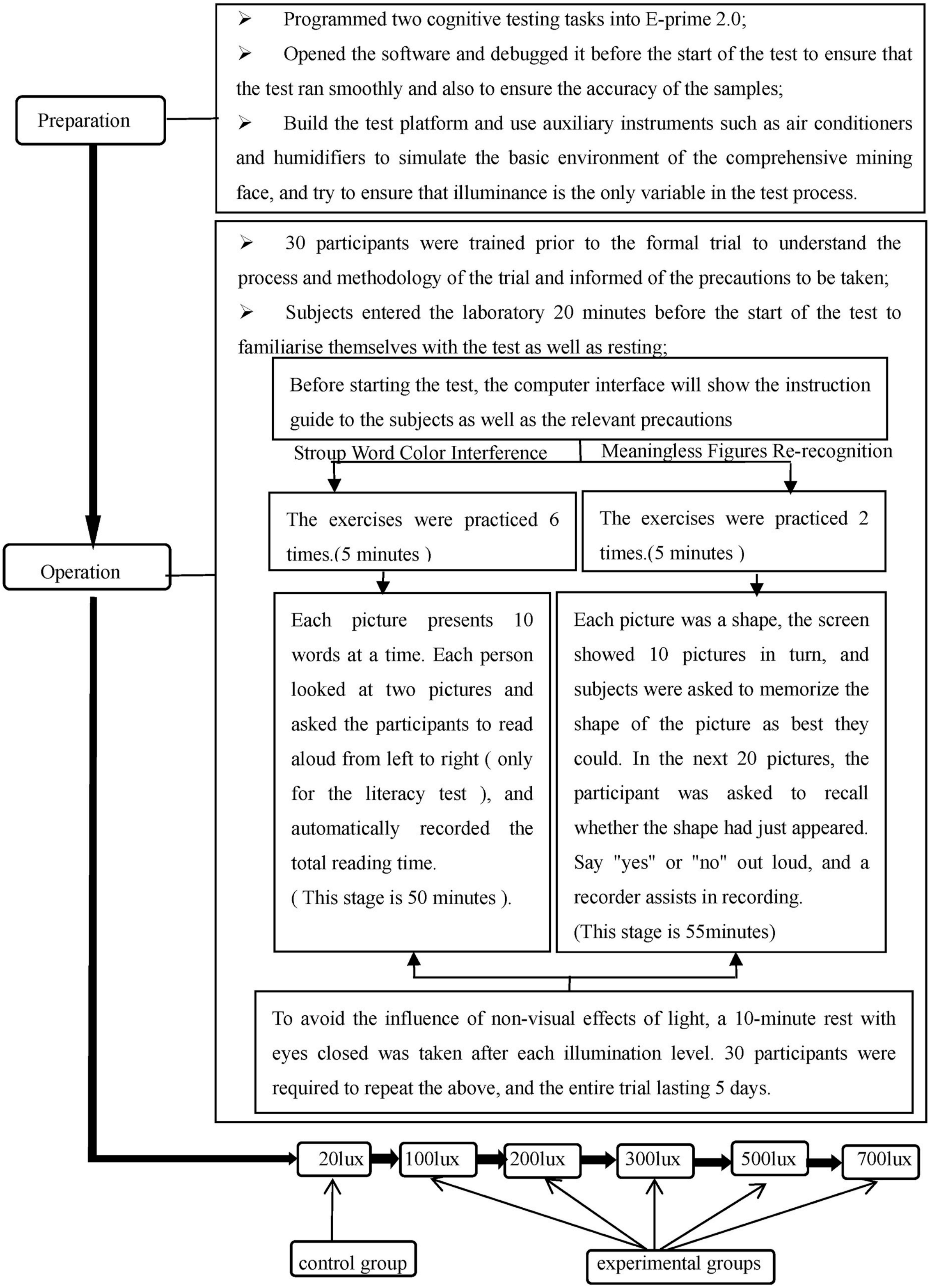

Fig. 5. Flowchart of experimental design and process(2-column fitting image).

Table 2
Descriptive statistics of Stroop word color interference test indicators at different illumination levels.

	Illumination Level	N	Mean	Standard Deviation	Standard Error	95 % Confidence Interval of Mean		Minimum	Maximum
						Lower	Upper		
AC	20lux	30	86.9067	2.57815	0.47070	85.9440	87.8694	80.10	90.10
	100lux	30	84.4300	3.36812	0.61493	83.1723	85.6877	78.90	90.10
	200lux	30	86.0067	3.00022	0.54776	84.8864	87.1270	80.10	92.50
	300lux	30	96.1067	2.20265	0.40215	95.2842	96.9292	92.10	99.50
	500lux	30	93.3000	2.58310	0.47161	92.3355	94.2645	86.50	96.80
	700lux	30	90.2433	2.82802	0.51632	89.1873	91.2993	84.60	95.70
RT	20lux	30	11.4500	0.76101	0.13894	11.1658	11.7342	10.20	12.80
	100lux	30	11.5633	0.73788	0.13472	11.2878	11.8389	10.20	13.10
	200lux	30	10.7567	0.80630	0.14721	10.4556	11.0577	9.50	12.60
	300lux	30	10.4400	0.80584	0.14713	10.1391	10.7409	9.20	12.30
	500lux	30	11.1800	0.81130	0.14812	10.8771	11.4829	9.60	12.30
	700lux	30	11.8467	0.89432	0.16328	11.5127	12.1806	9.90	13.40
PI	20lux	30	8.3433	0.44697	0.08161	8.1764	8.5102	7.10	9.20
	100lux	30	8.5500	0.35888	0.06552	8.4160	8.6840	8.10	9.20
	200lux	30	8.9533	0.40063	0.07315	8.8037	9.1029	8.30	9.60
	300lux	30	9.2533	0.33706	0.06154	9.1275	9.3792	8.40	9.80
	500lux	30	8.8767	0.38568	0.07041	8.7327	9.0207	7.90	9.40
	700lux	30	8.7000	0.37783	0.06898	8.5589	8.8411	8.00	9.30

Table 3
Descriptive statistics of Meaningless figure recognition test test indicators at different illumination levels.

	Illumination Level	N	Mean	Standard Deviation	Standard Error	95 % Confidence Interval of Mean		Minimum	Maximum
						Lower	Upper		
AC	20lux	30	91.5000	3.74451	0.68365	90.1018	92.8982	83.50	95.60
	100lux	30	92.8300	2.36252	0.43133	91.9478	93.7122	86.40	96.70
	200lux	30	97.1633	1.28371	0.23437	96.6840	97.6427	94.50	98.90
	300lux	30	97.1467	1.29847	0.23707	96.6618	97.6315	94.50	98.90
	500lux	30	94.0267	1.96274	0.35835	93.2938	94.7596	89.70	97.50
	700lux	30	90.8367	2.00353	0.36579	90.0885	91.5848	86.50	94.50
RT	20lux	30	12.2867	0.73378	0.13397	12.0127	12.5607	11.20	13.40
	100lux	30	13.4100	0.82935	0.15142	13.1003	13.7197	11.60	14.70
	200lux	30	12.1467	0.74913	0.13677	11.8669	12.4264	10.90	13.70
	300lux	30	11.2067	0.76200	0.13912	10.9221	11.4912	9.80	12.80
	500lux	30	12.4233	0.72191	0.13180	12.1538	12.6929	10.60	13.60
	700lux	30	14.1567	0.71856	0.13119	13.8884	14.4250	12.40	15.40
PI	20lux	30	8.8300	0.34953	0.06382	8.6995	8.9605	8.00	9.40
	100lux	30	8.0300	0.25751	0.04701	7.9338	8.1262	7.60	8.50
	200lux	30	9.0900	0.39510	0.07213	8.9425	9.2375	8.20	9.70
	300lux	30	9.3733	0.37777	0.06897	9.2323	9.5144	8.30	9.80
	500lux	30	8.5667	0.33869	0.06184	8.4402	8.6931	7.70	9.20
	700lux	30	8.3167	0.29371	0.05362	8.2070	8.4263	7.50	9.00

20lx, the PI value is the lowest. With the increase of illumination level, the PI value increases continuously, and reaches the maximum value at 300lx. However, at this time, the PI value decreases rapidly with the increase of illumination level. After adapting to the high illumination level, the decline rate slows down.

Analysis of AC, RT and PI found that changes in illuminance levels affect light, which in turn affects visual cognitive information processing. With the increase of illumination value, the load of information processing is different. 0–300 lux, people can 't see clearly from the vision to the rapid improvement of cognitive ability. With the increase of illumination value, the cognitive ability will have a marginal effect, and its improvement gradually slows down. When the illumination value is 300 lx, the index values basically tend to be stable. At this time, the cognitive ability of human visual recognition reaches a maximum value, and no longer increases with the increase of illumination. Even when the illumination exceeds 300 lux, it increases to a certain extent to produce glare. At this time, the cognitive ability of human visual recognition shows a downward trend. When the illumination increases to a certain extent, people 's visual recognition cognitive ability tends to decline.

In order to identify the factors with significant effects clearly, the interaction between the factors and the optimal level of the factors with significant effects, an analysis of variance (ANOVA) of the indicators was performed. As shown in Table 6.

As shown in Table 6, most of the P-values$>$0.05 in accuracy (AC) and composite performance indicators (PI) in Stroop word color interference test indicate that there is no significant difference between these two indexes and different illumination levels, while the reaction time (RT) has a significant difference with the illumination level.

From Fig. 6 and Table 6, linear regression analysis can be carried out for PI of Stroop word color interference test, and model b is

Table 4
Between-subjects effects of Stroop word color interference test indicators at different illumination levels.

Source Significance	Dependent Variable	Class III Sum of Squares	Degree of Freedom	Mean Square	F	Significance	Bias Eta Square
Modified model	AC	3098.227[a]	5	619.645	79.93	<0.001	0.697
	RT	41.610[b]	5	8.322	12.865	<0.001	0.27
	PI	15.402[c]	5	3.08	20.67	<0.001	0.373
Intercept	AC	1441809.2	1	1441809.2	185982.98	<0.001	0.999
	RT	22603.847	1	22603.847	34944.15	<0.001	0.995
	PI	13874.156	1	13874.156	93094.79	<0.001	0.998
Illumination	AC	3098.227	5	619.645	79.93	<0.001	0.697
	RT	41.61	5	8.322	12.865	<0.001	0.27
	PI	15.402	5	3.08	20.67	<0.001	0.373
Error	AC	1348.913	174	7.752			
	RT	112.553	174	0.647			
	PI	25.932	174	0.149			
Total	AC	1446256.34	180				
	RT	22758.01	180				
	PI	13915.49	180				
Revised Total	AC	4447.14	179				
	RT	154.163	179				
	PI	41.334	179				

AC.R-squared = 0.697 (adjusted R-squared = 0.688).
RT.R-squared = 0.270 (adjusted R-squared = 0.249).
PI.R-squared = 0.373 (adjusted R-squared = 0.355).

Table 5
Between-subjects effects of Meaningless figure recognition test test indicators at different illumination levels.

Source Significance	Dependent Variable	Class III Sum of Squares	Degree of Freedom	Mean Square	F	Sig.	Bias Eta Square
Modified model	AC	2499.696[a]	5	499.939	61.031	<0.001	0.637
	RT	72.773[b]	5	14.555	28.899	<0.001	0.454
	PI	20.418[c]	5	4.084	28.988	<0.001	0.454
Intercept	AC	1419521.284	1	1419521.284	173289.593	<0.001	0.999
	RT	22659.912	1	22659.912	44991.609	<0.001	0.996
	PI	13466.32	1	13466.32	95592.834	<0.001	0.998
Illumination	AC	2499.696	5	499.939	61.031	<0.001	0.637
	RT	72.773	5	14.555	28.899	<0.001	0.454
	PI	20.418	5	4.084	28.988	<0.001	0.454
Error	AC	1425.341	174	8.192			
	RT	87.635	174	0.504			
	PI	24.512	174	0.141			
Total	AC	1423446.32	180				
	RT	22820.32	180				
	PI	13511.25	180				
Revised Total	AC	3925.036	179				
	RT	160.408	179				
	PI	44.93	179				

AC.R-squared = 0.637 (adjusted R-squared = 0.626).
RT.R-squared = 0.454 (adjusted R-squared = 0.438).
PI.R-square = 0.454 (adjusted R-square = 0.439).
$P < 0.001$, the inter-group effect test has significant differences, and the data can be analyzed. Next, the specific change relationship between the data can be found through Origin 2018 mapping.

established as the linear regression model of different illumination levels and PI, as shown in Table 7.

From the analysis of the results observed in Tables 7 and it can be concluded that the significance level is 0.0057, which is less than 0.05 and model b is significant. The above results can indicate that the establishment of this regression model has analytical significance and the next regression analysis is carried out as shown in Table 8.

From Table 8: In model b the significance of constant and time is less than 0.05, both results are significant, it can be seen that the constant and time have analytical significance, which establishes the binary linear regression equation between the different illumination levels and the overall PI of the Stroop word color interference as:

$$y = 8.23184 + 0.00481x - 0.000006079x^2 \tag{1}$$

Where X is the illumination level (lux) and Y is the composite performance PI (%)

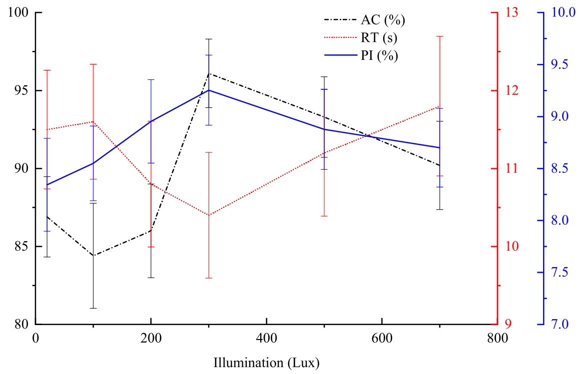

Fig. 6. Variation of AC and RT indexes in different illumination levels of Stroop word color interference test.

Table 6
Variance Analysis of various indexes of Stroop word color interference test under different illumination.

	20lux		100lux		200lux		300lux		500lux		700lux	
	F	P	F	P	F	P	F	P	F	P	F	P
AC	9.236	0.064	10.841	−0.031	9.864	0.056	9.854	0.021	11.973	0.089	8.796	0.102
RT	9.826	0.003	16.841	0.023	20.963	0.001	8.746	−0.012	11.634	−0.032	10.142	0.061
PI	5.874	0.076	12.362	0.023	8.743	0.061	6.536	1.023	8.794	0.078	9.283	−0.031

F: statistical value, P: statistical significance level.

Table 7
The different illumination levels-PI variance analysis table.

Model b	Square sum	df	Mean square	F	Sig.
Regression	0.51103	2	0.25551	8.61576	0.0057
Residuals	0.08897	3	0.02966	–	–
Total	0.6	5	–	–	–

df: degree of freedom; F: statistic; Sig.:statistical significance level.

Table 8
The different illumination levels-PI regression coefficient table.

Model b	Unstandardised coefficient		Standard deviation	t	Sig.
	B	Standard errors	Trial version		
B_1	0.00481	0.00116	–	−0.00013	<0.001
B_2	−0.000006079	0.000001558	–	0.000024	<0.001
Illumination	8.23184	0.16096	0.75286	1.0968	<0.001
R^2	0.373				
Adjusted R^2	0.355				
F	F = 20.670	p< 0.001			

B, B_1, B_2: regression coefficients t: statistical value; sig.: statistical significance level.

3.3. Trends and regression analysis of AC, RT and PI indicators of the meaningless figure recognition test

The Meaningless figure recognition test of the original test data imported into the software Origin 8.0 and plotted in Fig. 7.

As shown in Fig. 7, for the reaction time (RT) line graphs, the initial illumination level of 20lux reaction time is 12.3s, the illumination level increases, the reaction time becomes longer, the illumination level is higher than 100lux, the reaction time starts to shorten and the reaction starts to become faster, for the Meaningless figure recognition test the reaction time is shortened all the way up to 300lux, which has the fastest reaction and takes the shortest amount of time, and then increasing the illumination level affects again the At this point, if the illumination is increased, it will affect the subjects' responses again, making the response time longer.

For the accuracy (AC) line, when the illumination level is lower than 200lux, as the illumination level continues to rise, the accuracy rate also continues to rise, and it can be seen that the rate of increase of the accuracy rate when the illumination level is higher than 100lux is significantly higher than that when the illumination level is 20–100lux, when the illumination level is higher than 100lux and continues to raise the illumination level, the accuracy rate continues to rise, and the accuracy rate reaches the maximum

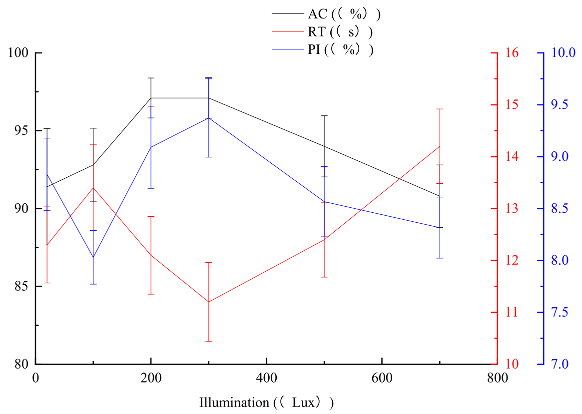

Fig. 7. Variation of AC and RT indexes with different illmination levels in Meaningless figure recognition test test

value and remains basically unchanged when the illumination level is higher than 100lux and continues to rise. Maximum value and basically unchanged, when the illumination level is higher than 300lux, the accuracy rate decreases and there is no relief trend.

For the performance indicators (PI) line, this folded line shows the trend in the performance indicators of the Meaningless Figure Recognition Test at different levels of illumination, reflecting the accuracy per unit of time. Initial illumination level of 20lux, the PI value of 8.8 %, the illumination level increases, the PI value declines, 100lux for the lowest value, at this time as the illumination level increases, the PI value gradually increases, in the 200–300lux is the rate of increase slowed down to 300lux to reach the maximum value, with the illumination level rises again, the PI value began to decline, can be seen when the high illumination level is adapted to As the illumination level increases again, the PI value starts to decrease.

In order to identify the factors that have a significant effect more clearly, the interaction between the factors and the optimal level of the significant effect factors, the indicator ANOVA was conducted. As shown in Table 9.

From Tables 9 and it can be seen that most of the P-values >0.05 in accuracy (AC) and reaction time (RT) in the Meaningless figure recognition test indicate that these two indicators are not significantly different from different illumination levels, while the overall performance indicators (PI) has a significant difference with illumination levels.

From Fig. 7 and Tables 9 and it was found that a linear regression analysis could be performed on the reaction time RT of the Meaningless figure recognition test, and the model c was established as a linear regression model of different illumination levels and RT, as shown in Table 10.

From the analysis of the results observed in Tables 10 and it is concluded that the significance level is 0.0019, which is less than 0.05, and model c is significant. The above results can indicate that the establishment of this regression model has analytical significance and the next regression analysis can be carried out as in Table 11.

From Table 11: In model c the significance of constant and time is less than 0.05, both results are significant, it can be seen that the constant and time have analytical significance, which establishes the binary linear regression equation between the different illumination levels and the reaction time RT of the meaningless figure recognition test as:

$$Y = 13.14337 + 0.000014875X\text{-}0.00899X^2 \ (X \geqq 100\text{lux}) \tag{2}$$

Where X is the illumination level (lux), Y is the reaction time RT (s)

4. Discussions

Descriptive statistics, ANOVA and correlation analysis were used to analyze the three indicators AC, RT and PI selected for cognitive test tasks. Different illumination levels had significant correlations with RT and PI, and no statistically significant main effect was found with AC performance. For different cognitive test tasks, the relationship between illumination level and indicators had different trends and significant differences. This research idea is consistent with previous theories. The effect of light on task performance depends on task type [19,22,23,42–45], which proves that it is feasible to rely on this scheme for quantitative comparison.

Table 9
Variance Analysis of each index of Meaningless figure recognition test under different illumination.

	20lux		100lux		200lux		300lux		500lux		700lux	
	F	P	F	P	F	P	F	P	F	P	F	P
AC	8.764	0.053	10.376	0.043	8.795	0.045	8.795	0.075	14.633	0.064	8.854	0.872
RT	7.643	0.087	14.753	0.076	19.263	0.098	6.847	−0.046	10.534	−0.097	12.176	0.074
PI	6.745	0.024	10.847	0.092	8.956	0.037	7.534	1.004	7.648	0.043	8.758	−0.042

F: statistical value, P: statistical significance level.

Table 10
The different illumination levels-RTvariance analysis table.

Model c	Square sum	df	Mean square	F	Sig.
Regression	3.70531	2	1.85265	3.02937	0.0019
Residuals	1.83469	3	0.61156	–	–
Total	5.54	5	–	–	–

df: degree of freedom; F: statistic; Sig.:statistical significance level.

Table 11
The different illumination levels-RT regression coefficient table.

Model c	Unstandardised coefficient		Standard deviation	t	Sig.
	B	Standard errors	Trial version		
B_1	−0.00899	0.00529	–	−0.0012	<0.001
B_2	0.000014875	0.000007077	–	0.0000049	<0.001
Illumination	13.14337	0.73092	0.44805	1.8754	<0.001
R^2	0.454				
Adjusted R^2	0.438				
F	F = 28.899	p< 0.001			

B, B_1, B_2: regression coefficients t: statistical value; sig.: statistical significance level.

However, a consistent pattern of the direction and size of these effects has not been found, and subsequent supplementary experiments can be carried out on this idea.

It can be seen from the change diagram of cognitive test task index and illuminance level that when the illuminance level is very low, the AC value is not high, and the illuminance level is higher than 100 lux. With the increase of illumination level, the visual effect increases, and the accuracy (AC) in the cognitive test task begins to increase, reaching the maximum value at 200 lux–300 lux. At this time, the illumination level increased again, and the AC value decreased, but the decline rate slowed down after the subjects adapted to this illumination level. When the light intensity is less than 100 Lux, with the increase of light intensity, the RT value increases, that is, the response of the subject slows down. Too low illumination will affect the response speed of the subject. When the light intensity is greater than 100 Lux and less than 300 Lux, the RT value decreases and the response becomes faster. Interestingly, when the light intensity is higher than 300 Lux, the increase of light intensity will still increase the RT value and slow down the reaction, which is caused by glare, affecting human vision and thus affecting cognitive processing. For the PI value, when the illumination level is lower than 200Lux, the results of the two cognitive ability tests are not the same, and the different cognitive test tasks will also lead to inconsistent responses of the subjects. However, when the illumination level is between 200Lux and 300Lux, the PI value is larger, and the accuracy rate per unit time is improved. When the light level is too high, the PI value decreases, and the decline rate of the subjects after adapting to the light level becomes slower.

The three indicators of AC, RT and PI selected in the cognitive ability test are used to express the required ' psychological index quantization value '. This provides a new way to predict the psychological state of miners in coal mines. The research on lighting at home and abroad is more common in indoor lighting, and there are relatively few studies on underground lighting in coal mines. The research on underground lighting is mostly based on the design of underground lighting lamps [46,47], the influence of lighting on human vision and behavior [48–51], and the influence of illumination on physiology [52,53]. The cognitive processing related to psychology is basically based on theoretical analysis. There are few quantitative studies on the bad environment of underground illumination and the psychological indicators of miners. This study quantitatively expresses the influence of illumination environment on human cognitive ability by simulating the combination of underground lighting level and psychological indicators, which has guiding significance for safety production.

There are still some limitations in the experiment:There are limitations in the control of the simulated environment; the laboratory simulated the environment of a general mine workface, which is a complex environment; In the cognitive ability test experiment, due to the limited time and experimental capacity, the relationship between the cognitive test and the length of time was not considered.

5. Conclusions

In this paper, the effect of illumination level on psychological indicators of miners was studied. This study combined the quantification of psychological indicators with underground illumination in coal mines, filling a gap in existing research.By controlling different illumination levels as variables, subjects were tested for their cognitive abilities, and three performance task indicators, AC, RT and PI, were selected to judge the changes of different illumination levels on miners' psychological state, which in turn affects the cognitive task output. The results showed that.

(1) The regression analysis of the three indicators and the illuminance level shows that the illuminance has significant differences with PI and RT. The binary linear regression equations between different illuminance levels and the overall performance indicators PI and RT are established respectively to quantify the effects of different illuminance levels on psychological indicators.

(2) Quantifying the control of the psychological level can help to determine the psychological threshold of the operator 's man-made accidents, establish an early warning system for the psychological indicators of the operator in the poor light operating environment, and reasonably control the lighting environment can effectively promote the cognitive ability of the miners in the work,it provides a theoretical basis for monitoring the psychological state of coal miners and arranging working hours, and minimizes the risk of coal mine accidents.
(3) Cognitive ability affects safe working conditions, and follow-up studies be conducted around the effects of illumination levels and miners' work efficiency in the mining face.

Data availability

Data will be made available on request.

CRediT authorship contribution statement

Yi Chai: Writing - original draft, Formal analysis, Data curation, Writing - review & editing. **Yungang Wang:** Writing - review & editing, Funding acquisition. **Feiyan Zhang:** Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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