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Research on regulated biological regularity LED light source based on normality test algorithm

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Abstract: In this paper, the optimal channel weight combination and the key parameters of the synthesized spectrum are obtained respectively for the two scenes of daytime illumination mode and night sleep aid mode (CCT, Duv, Rf, Rg, mel − DER). The question of whether "optimal lighting" has a beneficial effect on sleep quality compared to "normal light" and "dark environment", we first used genetic algorithms (GA), a multichannel spectral synthesis model is established, and then five key performance indexes are solved and optimized. Then, the overnight sleep data of 11 subjects in three environments were processed. Six groups of data including total sleep time, sleep efficiency, sleep latency, deep sleep proportion, rem sleep proportion and wake times were extracted. Next, using the normality test model, we pass the KS test and SW test, concluded that "optimal light" does not improve sleep quality compared with "normal light" and "dark environment".

Keywords: Intelligent optimization algorithm; Genetic algorithms (GA); Normality test model; KS test; SW test

1 INTRODUCTION

As a new type of light source that is highly efficient, energy-saving and environmentally friendly, Light-emitting diode (Light Emitting Diode, LED) [1] has been widely applied in multiple fields in recent years. In the field of lighting, the efficiency of white leds has far exceeded that of traditional incandescent lamps and fluorescent lamps, making them the most important lighting source at present. They can adapt to different lighting requirements by adjusting color temperature and spectral characteristics.

Scientific research shows that light not only provides us with visual illumination but also profoundly affects the body's physiological rhythm system through the retina [2]. For instance, light of specific wavelengths can affect the secretion of melatonin, thereby regulating our sleep quality, cognitive function and emotional state. Appropriate light regulation can enhance work efficiency, while inappropriate light may disrupt the normal circadian rhythm. Therefore, how to optimize the spectral characteristics of LED light sources while meeting the lighting requirements to achieve beneficial physiological rhythm regulation effects has become an important issue that needs to be urgently addressed. To better address these issues, this article raises two questions for in-depth discussion.

For the two scenarios of daytime lighting mode and nighttime sleep aid mode, the optimal channel weight combinations were respectively obtained, and the key parameters of the synthetic spectrum (CCT, Duv, Rf, Rg, mel − DER) were calculated. A mathematical model was established for the proposed problem, which can establish a multi-objective and multiconstraint nonlinear optimization problem, and a multi-channel spectral synthesis model can be established, combining the correlated color temperature with the distance from the Planck trajectory, the fidelity index (Rf) and color gamut index (Rg) and melatonin daily illuminance ratio (mel − DER). After these key performance indicators are calculated, numerical optimization methods can be adopted to solve them.

Then, regarding whether "optimized lighting" has a beneficial improvement on sleep quality compared to "normal lighting" and "dark environment", since it is necessary to draw conclusions based on the full-night sleep data of the given 11 subjects in the three environments, it is necessary to prioritize the analysis of the data. After obtaining six sets of data including total sleep time, sleep efficiency, latency to fall asleep, proportion of deep sleep, proportion of REM sleep, and the number of times one wakes up at night, a normal test model [3] can be established and the conclusion can be verified through the KS test [4] and SW test [5].

2 RELEATED WORK

The problems that need to be addressed in this paper are as follows:

For the two scenarios of daytime lighting mode and nighttime sleep aid mode, the optimal channel weight combinations were respectively calculated, and the key parameters of the synthetic spectrum (CCT, Duv, Rf, Rg, mel − DER)were also determined. Our team collected the wavelengths (nm) and corresponding spectral powers (W/nm) of red light, green light, blue light, warm white light and cold white light, transformed the data and used intelligent optimization algorithms to solve them. In addition, to ensure the physical rationality of the spectrum, the weights of each channel must be non-negative, and normalization (Constant total power) conditions can be set. The optimal spectrum obtained from the solution should be verified again using the parameter model in question One. The two scenarios are independent of each other, so they can be optimized separately.

In response to whether "optimized lighting" has a beneficial improvement on sleep quality compared to "normal lighting" and "dark environment", our team has collected data and established a mathematical model of the relationship between lighting conditions and sleep quality under three different conditions: "optimized lighting", "normal lighting", and "dark environment". To better analyze the status of sleep quality, Process the data of the collected 11 people The Total Sleep Time (TST), Sleep Efficiency (SE), and Sleep Onset were calculated Six sets of data including Latency (SOL), proportion of deep sleep (N3%), proportion of REM sleep (REM%), and Number of Awakenings at night A normality test model between lighting conditions and sleep quality under three different conditions, namely "optimized lighting", "normal lighting" and "dark environment", was established.

3 MODEL ESTABLISHMENT AND SOLUTION

3.1 Intelligent optimization model

3.1.1 Intelligent optimization modeling

The optimal channel weight combination and the key parameters of the synthesized spectrum are obtained for the two scenes of daytime daytime lighting mode and night sleep aid mode (CCT , Duv , Rf , Rg , mel − DER).

To solve the five core parameters, we need to constrain the conditions and build a preliminary model:

(1) Color Property Parameters:

① CCT :

Calculation of correlated color temperature based on tristimulus value xyz space:

Given SPD P(λ), the light source tristimulus value x, y, z the expression for is:

$$\begin{cases} X = k \int P(\lambda) \cdot \bar{x}(\lambda) d\lambda \\ Y = k \int P(\lambda) \cdot \bar{y}(\lambda) d\lambda \\ Z = k \int P(\lambda) \cdot \bar{z}(\lambda) d\lambda \end{cases} \tag{1}$$

In the above formula: K is scale factor; $\overline{x}(\lambda)$, $\bar{y}(\lambda)$ and $\overline{z}(\lambda)$ is the color function of CIE1931.

By triple stimulus value x, y, z the relevant expressions of chromaticity coordinates x and y for CIE 1931 and chromaticity coordinates u and v for cie 1960 can be calculated as follows:

$$\begin{cases} x = \frac{X}{X+Y+Z} \\ y = \frac{Y}{X+Y+Z} \end{cases} \tag{2}$$

$$\begin{cases} u = \frac{4X}{X+15Y+3Z} \\ v = \frac{Y}{X+15Y+3Z} \end{cases} \tag{3}$$

Compute cct in kelvin k from the chromaticity coordinate (x, y) find the point closest to (u, v) on the Planck trajectory, the temperature corresponding to the nearest distance is solved by iterative method, which is the correlated color temperature (CCT).

②Distance from Planck's trajectory (Duv):

Calculating the Euclidean distance between (u, v) and the nearest point (u_0, v_0) on the Planck locus:

$$Duv = \min_{T} \sqrt{(u - u_0)^2 + (v - v_0)^2} \tag{4}$$

(2) Color Restore Parameters:

①Fidelity Index (Rf):

Rf is a measure of the ability of the light source to restore the color of the object, that is, the color similarity compared to the reference light source (The standard light source under the same CCT). It is based on the calculation of the color difference under the n color evaluation sample test and reference light sources. It is calculated as follows:

Calculate the chromaticity deviation of n test samples between the test color sample and the reference color sample:

$$\Delta Ei = \sqrt{(u_{m,i} - u_{n,i})^2 + (v_{m,i} - v_{n,i})^2} \tag{5}$$

Fidelity Index (Rf):

$$Rf = 100 - 4.6 \cdot \frac{1}{n} \sum_{i=1}^{n} \Delta E_i \tag{6}$$

When Rf = at 100, the color is the same as the reference light source; when Rf < 100, the color is different, and the lower the value, the bigger the difference.

②Gamut Index (Rg):

Rg measures the overall effect of the light source on color saturation, that is, the change in color gamut area relative to the reference light source. Its calculation formula is:

$$Rg = \frac{A_t}{A_s} \times 100\% \tag{7}$$

Where A_t is the area corresponding to the test light source and A_s is the area corresponding to the reference light source.

After the initial model is established, the light sources which slowly meet the specific spectral requirements are synthesized by weighted linear superposition, and the optimal channel weight combination and spectral parameters are obtained for daytime illumination mode and night sleep aid mode, respectively. To this end, the following mathematical models are established:

(1) Multichannel spectral synthesis model Each of the five channels is represented as $S_1(\lambda),...,S_5(\lambda)$,Its drive weight is w_i. Then we build composite models as follows:

$$S_{min}(\lambda) = \sum_{i=1}^{5} w_i S_i(\lambda), w_i \geq 0, \sum_{i=1}^{5} w_i = 1 \tag{8}$$

Among them,w_i represents the weight of the i-th channel, which meets the non-negative constraint. The fifth channel is: Blue 、Green、Red、Warm White,WW and Cold White,CW.

(2) Calculation of spectral performance parameters for the synthetic spectrum $S(\lambda)$, calculate the following key performance metrics:

● Correlation color temperature and distance from Planck locus: Convert $S(\lambda)$ to CIV XYZ tristimulus value:

$$\begin{cases} X = \int S(\lambda)\bar{x}(\lambda)\, d\lambda \\ Y = \int S(\lambda)\bar{y}(\lambda)\, d\lambda \\ Z = \int S(\lambda)\bar{z}(\lambda)\, d\lambda \end{cases} \tag{9}$$

Then convert it into chromaticity coordinates(X, Y), and use approximate formula to solve CCT and Duv.

● Fidelity Index (Rf) and Gamut Index (Rg) : A simplified TM-30 method is used to map spectral smoothness and color gamut distribution to approximate values of Rf and Rg.

● Melatonin insolation ratio $(mel - DER)$:The CIES 026 melanopic spectral sensitivity function $M(\lambda)$ is introduced, the calculation formula is:

$$mel - DER = \frac{\int S(\lambda)\cdot m_1(\lambda)\cdot d\lambda}{\int S_{ref}(\lambda)\cdot m_2(\lambda)\cdot d\lambda} \tag{10}$$

(3) Optimization modeling for different scenarios, we define the following optimization problems:

Daytime lighting mode:

$$\max_{w} Rf\big(S(\lambda)\big) \tag{11}$$

$$s.t.\begin{cases} 5500 \leq CCT(S) \leq 6500, \\ 95 \leq Rg(S) \leq 105, Rf(S) \geq 88, \\ w_i \geq 0, \sum_{i=1}^{5} w_i = 1 \end{cases} \tag{12}$$

Night sleep aid mole:

$$\min_{w} mel - DER\big(S(\lambda)\big) \tag{13}$$

$$s.t.\begin{cases} 2500 \leq CCT(S) \leq 3500, \\ Rf(S) \geq 80, \\ w_i \geq 0, \sum_{i=1}^{5} w_i = 1 \end{cases} \tag{14}$$

(4) Solution method

Because the spectral synthesis and parameter calculation formulas are nonlinear and non-derivable, the numerical optimization method is used to solve the problem. In implementation: using SciPy. Optimize, combined SLSQP [6] vs. L-BFGS-B [7] Algorithm; penalty term applied to infeasible solution:

$$f_{penalized} = f_{objective} + \sum_j a_j \cdot max\big(0, amount\_of\_default_j\big) \tag{15}$$

If the gradient optimization is convergent, the heuristic initialization method is used to give a feasible approximate solution.

3.1.2 Intelligent optimization model solution

We visualized the results to get the following related graphs:

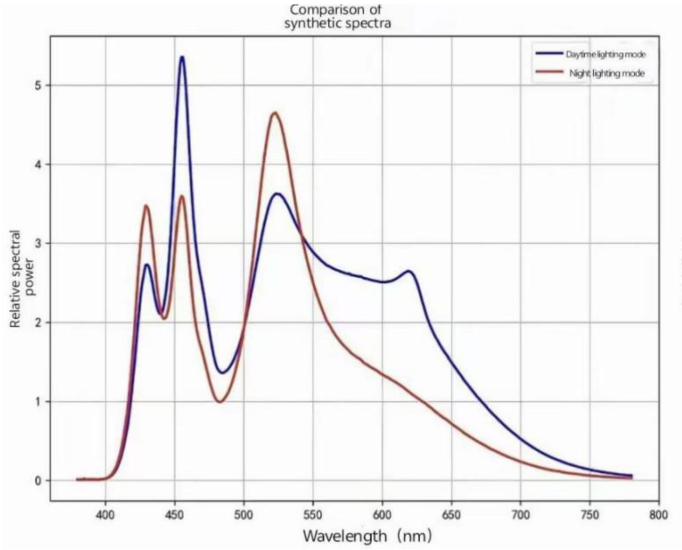


Fig. 1: The relationship between wavelength and relative spectral power in two lighting modes.

Daytime lighting mode: spectrum in blue (400-500nm) and green-yellow (500-600nm) regions have multiple peaks, high relative spectral power, covering melatonin sensitive band and human visual sensitive area, it can meet the needs of high illumination and clear vision in daytime, but it may contain more blue and green light, which inhibits melatonin secretion and keeps awake.

Night sleep aid mode: the spectral peak is lower than daytime, the proportion of blue-green light is reduced, and the red-yellow light (500-600nm and above) is relatively prominent. Reduce the interference of melatonin secretion, build a sleep-aiding light environment, and reduce physiological arousal.

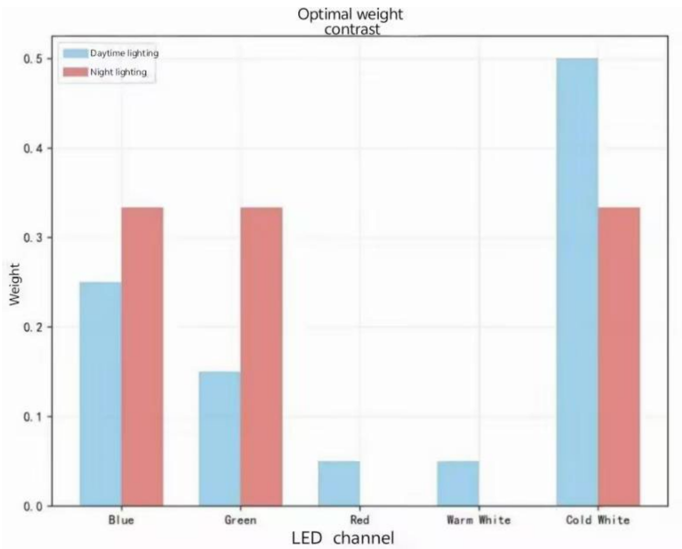


Fig. 2: Comparison of optimal weights of two lighting modes.

Daytime lighting: the weight of cold and white is significantly higher (About 0.5), with a certain proportion of blue and green (About 0.25 for blue and even lower for green), and the weight of red and warm white is extremely low. Reflect the daytime need for high brightness, cold tonal light environment, cold white and others can provide the daytime vision and physiological wake up requirements of the spectrum.

Night sleep aid: the weight of blue, green and cold white is obviously lower than that of daytime, and the weight of red and warm white is relatively stable (About 0.3 for blue and green and about 0.3 for cold white). It is suggested that the weight of sensitive band (Such as blue-green light) to melatonin is reduced at night to reduce the inhibition of melatonin secretion, and part of the mild spectrum is preserved.

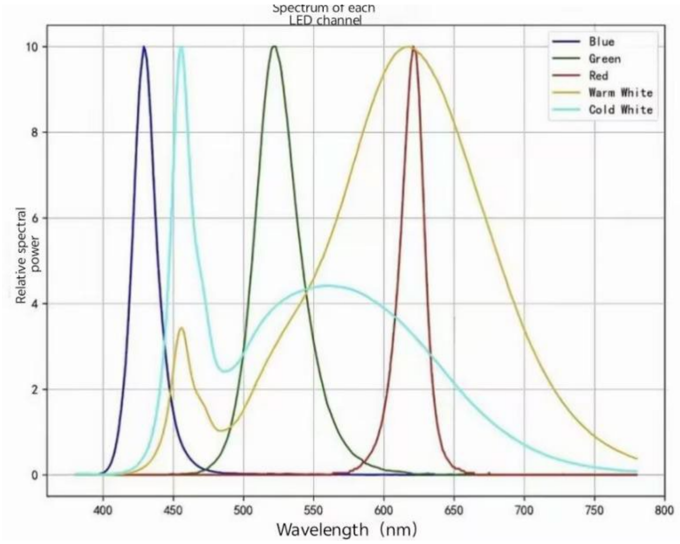


Fig. 3: The relationship between wavelengths and relative spectral power under each color.

Different LED channel spectral characteristics are distinct: blue in 400 - 500nm having narrow peaks; green concentrated in 500nm left and right; red peak in 600 - 700nm; warm white covered yellow-red band (500 - 700nm); cool white covers a wide range of blue-green to yellow-red. These basic spectra are combined with different modes of spectra in daytime and nighttime through weight adjustment, which is the underlying basis for realizing light environment function (Wake up/sleep aid).

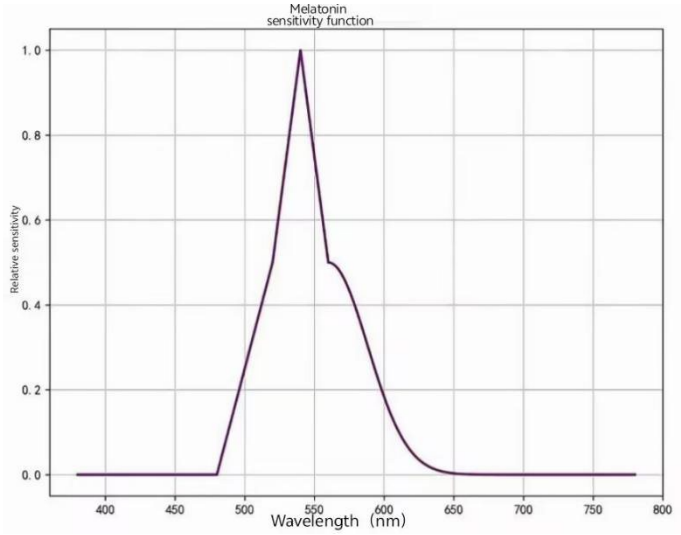


Fig. 4: Relative sensitivity of melatonin at different wavelengths.

Melatonin sensitivity showed significant selectivity with wavelength, at about 480-550 nm band (Estimated peak at in that range of 490 to 530 nm), the relative sensitivity rapidly increase to the peak value of 1.0, and then rapidly decrease, which indicate that the influence of light in this band on the regulation of melatonin secretion is key, it is the core function of light environment to interfere with circadian rhythm.

To sum up, the four graphs from melatonin sensitivity characteristics, led weight allocation, final spectral performance, basic channel spectrum, a complete picture according to the physiological rhythm needs (Daytime arousal, night sleep aid), the use of different LED spectral characteristics: the logic of light environment design: by regulating the spectral components (Such as the proportion of blue-green light) that affect the secretion of melatonin, matching the physiological needs of different time periods, provide theory and data support for the design of health lighting (Such as smart lamps, hospital/bedroom light environment).

3.2 Normality test model

3.2.1 Normality test modeling

To determine whether "optimal lighting" has a beneficial effect on sleep quality compared to "normal lighting" and "dark environment". We have the overnight sleep data of these 11 subjects in three environments (A total of 33 valid records), and we need to calculate the total sleep time through the given data through the problem analysis (Total Sleep Time, TST), sleep efficiency (Sleep Efficiency, SE)、 sleep latency (Sleep Onset Latency, SOL)、 proportion of deep sleep (n3%), proportion of rem sleep (REM%), number of wakes at night (Number of Awakenings) six sets of data, which can be analyzed to determine whether "optimal lighting" compared with "normal light" and "dark environment", produced a beneficial improvement in sleep quality.

Total sleep time: just add the number of items with the values of 2, 3, and 5 and multiply it by time. Here, the unit of this team is minutes.

Sleep Efficiency: Sleep efficiency is obtained by adding the number of items with the values of 2, 3, 4, and 5 to obtain the total bedtime, dividing tst by the total bedtime, and finally dividing the percentage sign:

$$Sleep\ efficiency = \frac{TST}{Total\ bed\ time} \times 100\% \tag{16}$$

Sleep latency: to calculate the time between waking up and starting to sleep, again in minutes.

Proportion of deep sleep: we calculate the total duration of n3 and divide it by tst. The proportion of deep sleep can be obtained by the last percentile approximation:

$$N3\% = \frac{Total\ duration\ of\ phase\ N3}{TST} \times 100\% \tag{17}$$

REM Sleep Proportion [8]: the total length of the rem period is calculated and divided by tst, the last percent sign is about to get the rem sleep ratio:

$$REM\% = \frac{Total\ duration\ of\ phase\ REM}{TST} \times 100\% \tag{18}$$

Number of Awakenigs: Count the total number of times you wake up after you start sleeping.

3.2.2 Normality test model solution

These six groups of data can be obtained through the above formula. Because there is a lot of data, the data is classified into "optimized lighting" according to the light environment classification (Night 1) Compared to "normal light" (Night 2) and "dark environment" (Night 3) The three categories are shown in Table 3 below:

Table. 1: Optimize the lighting (Night1).

The subject	Total sleep time/min	Sleep Efficiency	Sleep latency/min	Proportion of deep sleep	REM Sleep Proportion	Number of Awakenings
1	310	87%	15	15%	20%	19
2	322	66%	16	17%	32%	17
3	360.5	92%	4	21%	26%	12
4	354	89%	40.5	23%	32%	11
5	397.5	93%	16	27%	23%	14
6	382.5	90%	31	14%	15%	11
7	371	84%	31	19%	27%	6
8	381.5	89%	31	12%	14%	13
9	491	92%	6.5	20%	33%	17
10	342.5	85%	7	18%	34%	14
11	329.5	77%	23.5	21%	22%	10

Table. 2: Normal light (Night2).

The subject	Total sleep time/min	Sleep Efficiency	Sleep latency/min	Proportion of deep sleep	REM Sleep Proportion	Number of Awakenings
1	312	86%	2	25%	23%	18
2	348	75%	5	31%	30%	13
3	260	71%	51	28%	20%	14
4	386	94%	13	20%	42%	12
5	430.5	94%	16	9%	36%	15
6	358.5	75%	75	11%	22%	8
7	401.5	88%	47.5	20%	28%	8
8	375.5	88%	2	23%	21%	15
9	455.5	93%	13.5	20%	29%	24
10	453.5	96%	5.5	11%	27%	11
11	389.5	96%	8.5	16%	17%	11

Table. 3: Dark environment (Night3).

The subject	Total sleep time/min	Sleep Efficiency	Sleep latency/min	Proportion of deep sleep	REM Sleep Proportion	Number of Awakenings
1	288.5	82%	5	26%	26%	18
2	347	92%	0	28%	24%	16
3	259	68%	54.5	22%	24%	10
4	347	46%	7	34%	22%	9
5	384	84%	2	27%	18%	14
6	365	92%	2.5	26%	12%	10
7	379.5	94%	7	23%	8%	8
8	435	95%	2	37%	36%	12
9	437	96%	1.5	16%	20%	22
10	347	94%	9	18%	24%	7
11	367.5	87%	24	26%	19%	16

The above three tables are the data of three kinds of light environment on various sleep indicators. Through the above data, whether there is significant difference in the influence of three kinds of light environment on various sleep indicators is analyzed.

Due to previous studies [9], it is generally believed that q_t follows a log-normal distribution [4, 14]. To maintain consistency, this paper conducts a normality test on $\ln(q_t)$, that is, when q_t follows a log-normal distribution, $\ln(q_t)$ should follow a normal distribution. The normality test method generally adopts the following hypothesis forms:

H_0 indicates that the data follows a normal distribution.

H_1 indicates that the data does not follow a normal distribution.

According to different statistical characteristics (Such as skewness coefficient [10], kurtosis coefficient [11], distribution curve and correlation coefficient) applied, different normality test methods are derived, which are briefly introduced as follows:

(1) KS test (Kolmogorov-Sminov test)

The KS test belongs to the empirical distribution function test method. Its test statistics are defined as the maximum vertical difference between the theoretical distribution curve and the empirical distribution curve. Given n sorted data points $x_1 < x_2 < \ldots\ldots < x_n$, the KS test statistic T is defined as:

$$T = max|F^*(x) - F_n(x)| \tag{19}$$

In the formula: $F^*(x)$ is the theoretical cumulative distribution curve function; $F_n(x)$ is obtained by estimation from the sample. If the test statistic T exceeds the critical value $T_1 - a$ under the corresponding significance level α, H_0 is rejected. Expressed in terms of probability, if the P is greater than the significance level α, H_0 is not rejected. The KS test can be used to test whether sample data follows a normal distribution, and it can also test whether data follows other distributions [7]-[12]. For the normal distribution test, the mean and standard deviation of the theoretical distribution curve need to be given, but these two statistics are unknown. Therefore, when using the KS test, for any random sample with unknown distribution, the sample data should be standardized first and then used in the KS test.

(2) SW Test (Shapiro-Wilk Test)

The SW test is a method to test the non-normality of data caused by skewness and kurtosis, and it is widely recognized due to its good power. For a given random sample, after sorting, it is denoted as $x_1 < x_2 < \ldots\ldots < x_n$, then the SW test statistic W is defined as:

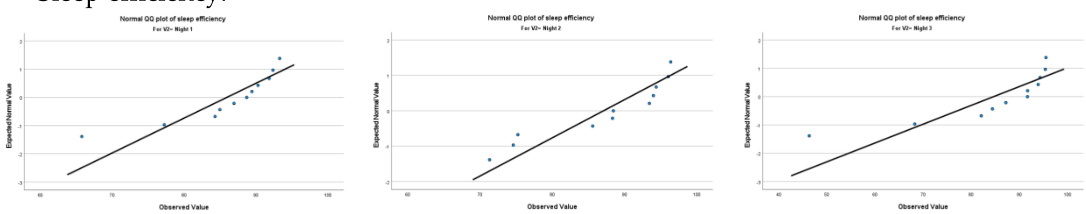
$$W = \left[\sum_{i=1}^{\frac{n}{2}} \alpha_i (x_{n+1-i} - x_i)^2\right] / \sum_{i=1}^{n} (x_i - \bar{x})^2 \tag{20}$$

In the formula: n is the sample size; x_i is the i-th order statistic; $\bar{x}$ is the sample mean; a_i is the weight coefficient, which can be obtained by checking the quantile table. The W statistics can be regarded as the ratio between the optimal variance estimator derived from the square of a certain linear combination of order statistics and the sample variance of the data. According to the given significance level α and sample size n, check the P-quantile table of the statistic W to determine the α-quantile critical value W_a. If $W < W_\alpha$, H_0 is rejected, and it is considered that the data does not follow a normal distribution; otherwise, H_0 is not rejected. The distribution of the W statistics has a large skewness, and a W value close to 1 may also lead to the rejection of the null hypothesis of normality. Since the critical values involved in different methods are different, in statistics, it tends to be expressed in the form of a probability value (P) to obtain a generalized judgment result. If $P = P(W \geq W_\alpha) > \alpha$, H_0 is not rejected. In this paper, the significance level α is taken as 0.05, which is consistent with common statistical analyses.

When the sample size $n \leq 50$, the result of the SW test is taken as the criterion, and when the sample size $n > 50$, the result of the KS test is taken as the criterion [12].

Based on the above modeling, normal QQ plots can be generated using SPSS software. Due to the large number of images, only the more important variable sleep efficiency, deep sleep ratio, and REM sleep ratio—are analyzed here:

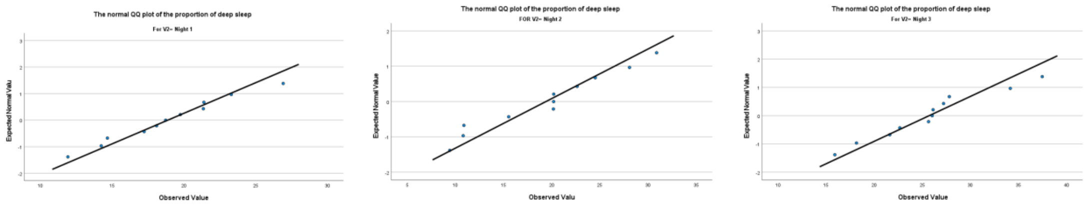
Sleep efficiency:



(a)Night 1 Normal QQ picture (b)Night 2 Normal QQ picture (c)Night 3 Normal QQ picture

Fig. 5: Normal QQ picture of Sleep Efficiency.

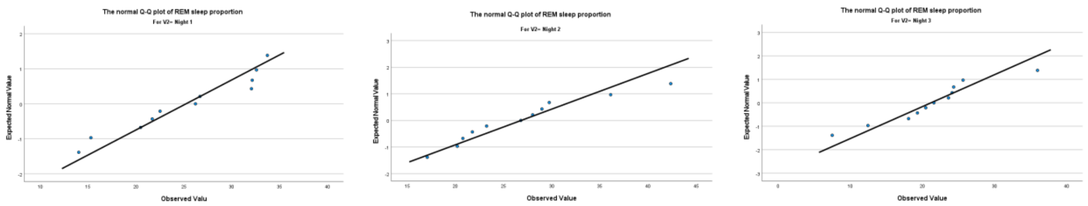
Proportion of deep sleep:



(a)Night 1 Normal QQ picture (b)Night 2 Normal QQ picture (c)Night 3 Normal QQ picture

Fig. 6: Normal QQ chart of deep sleep ratio.

REM Sleep Proportion:



(a)Night 1 Normal QQ picture (b)Night 2 Normal QQ picture (c)Night 3 Normal QQ picture

Fig. 7: REM sleep ratio normal QQ chart.

4 CONCLUSION

4.1 The results of the intelligent optimization model

This study addresses two scenarios: daytime lighting mode and nighttime sleep-assist mode. For each scenario, the optimal channel weight combination was determined, and key parameters of the synthesized spectrum, including (CCT , Duv , Rf , Rg , mel − DER)were calculated. The following data were obtained:

Daytime lighting:

$$w = \{0.24,0.16,0.05,0.050.46\},$$

$$CCT = 4419.7K,$$

$$R_f = 97.8,$$

$$R_g = 89.8.$$

$$mel - DER = 0.2371.$$

Night sleep aid:

$$w = \{0.3333,0.3333,0,0,0.3333\},$$

$$CCT = 4141.3K,$$

$$R_f = 98.9,$$

$$R_g = 86.2K,$$

$$mel - DER = 0.2891.$$

Then, regarding whether the "optimized lighting" has produced beneficial improvements in sleep quality compared to "ordinary lighting" and "dark conditions", the normality test table shows that the KS test indicates higher sleep efficiency in Night1 than in the other two conditions, while no improvement was observed in other metrics—in fact, it was even lower in some cases. The SW test only showed slightly higher values in sleep latency and deep sleep ratio compared to the other two conditions, but the differences were marginal. Therefore, it can be concluded that the "optimized lighting" did not improve sleep quality compared to "ordinary lighting" and "dark conditions".

4.2 The results of the normality test model

By building a model, we can obtain a normality test table for whether "optimal lighting" produces beneficial improvement on sleep quality compared with "normal lighting" and "dark environment":

Table. 4: Normality test.

		KS test			SW test		
		Count	Degree of freedom	Significence	Count	Degree of freedom	Significence
Sleep Efficiency	Night 1	0.239	11	0.079	0.811	11	0.013
	Night 2	0.208	11	0.198	0.851	11	0.044
	Night 3	0.251	11	0.051	0.743	11	0.002
Total sleep time	Night 1	0.198	11	.200*	0.868	11	0.074
	Night 2	0.117	11	.200*	0.955	11	0.704
	Night 3	0.224	11	0.128	0.932	11	0.429
Incubation period of falling asleep	Night 1	0.179	11	.200*	0.928	11	0.391
	Night 2	0.319	11	0.003	0.78	11	0.005
	Night 3	0.353	11	0	0.64	11	0
Proportion of deep sleep	Night 1	0.106	11	.200*	0.986	11	0.99
	Night 2	0.18	11	.200*	0.942	11	0.546
	Night 3	0.187	11	.200*	0.957	11	0.738
REM Sleep Proportion	Night 1	0.199	11	.200*	0.914	11	0.273
	Night 2	0.166	11	.200*	0.937	11	0.486
	Night 3	0.182	11	.200*	0.949	11	0.626
Number of Awakenings	Night 1	0.13	11	.200*	0.97	11	0.89
	Night 2	0.194	11	.200*	0.916	11	0.285
	Night 3	0.187	11	.200*	0.943	11	0.561

* This is the lower limit of true significance.

* A Rilly's significant correction

According to the table above, the data generally follows a normal distribution. The KS test indicates that for sleep efficiency, Night1 is higher than the other two conditions, whereas no significant differences were observed in other metrics—in fact, it was even lower in some cases.

The SW test only showed slightly higher values for sleep latency and deep sleep ratio compared to the other two conditions, but the differences were marginal.

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