



Validation of evaluation model and evaluation indicators comprised Kansei Engineering and eye movement with EEG: an example of medical nursing bed

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Abstract

The study is to innovate an evaluation model of medical nursing bed and verify indicators by triangulation of subjective feelings, eye movement and electroencephalography (EEG). The underlying theory is Kansei Engineering that is the technology to measure and transform consumers' perceptions of products into design elements. Kansei Engineering comprises external physiological sensory measurement and intrinsic psychological susceptibility measurement. The evaluation of medical nursing bed should measure subjective and objective data. The current evaluation method of medical nursing bed is very subjective and cannot be tested objectively. It is rationale to apply Kansei Engineering in medical nursing bed evaluation comprised subjective feelings and eye movement with electroencephalography. The methodology is the experimental research in which four design proposals of medical nursing bed were compared by 20 participants. Data collection adopted Tobii X2 eye tracker and NeurOne EEG recording system except subjective feelings. D-lab, ERGO-LAB, and EEGLAB was applied to process data of eye movement and EEG. Correlation of triangulation was analyzed for criterion-related validity. Cronbach's Alpha was used as a measure of internal consistency for reliability. Findings indicated design proposal 2 contained a rounded rectangular and line surface organically combined was optimal. Triangulation was supported as indicators for more objective and persuasive evaluation of medical nursing beds. Implications for practice will be applied in NCC Medical Co., LTD, Huashan Hospital Affiliated to Fudan University, Shanghai Ying Hand Medical Equipment Co., Ltd, and WUTRON SAPACE in Shanghai DianJi University. Implications for follow-up research is in proceeding with more participants.

1 Introduction

Design of nursing beds are varied from initial ordinary steel beds to mechanical transmission beds, electric nursing beds, and multifunctional nursing beds. The development of multifunctional nursing beds had been undergone several years by applying microcomputer technology in the science of nursing bed. It's a breakthrough that multifunctional nursing beds not only achieve comprehensive

nursing but also innovate the functions of health care for patients (Zhuang et al. 2018). The trend of multifunctional nursing beds is more networking, digital, and intelligent due to the development of information networks, sensors, intelligent control, bionic technologies, as well as the intersection of electromechanical technology and biotechnology (Sakamoto et al. 2001).

The higher of medical level, the much more pursuit of living standards and quality. Users not only ask products for the basic function, safety and practice but also pay more attention to the comfort, aesthetic and emotional desires of the product (Gelici Zeko et al. 2013; Nanda et al. 2016). However, the design of medical nursing bed is obviously lack of Kansei Engineering (Rau et al. 1982; Torta et al. 2014). As a result, it makes patients feel not only painful due to the sickness but also inconvenient out of the unreasonable design. For the patient, it is undoubtedly a great gospel to improve and promote the design of the medical nursing bed (Agwu et al. 2018).

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Most of the recent research concerning nursing bed concentrates on the function and user experience. Related studies on the function were focused on solving problems happened when patients and the caregivers used the nursing beds. For instance, Enoi et al. (2016) designed a smart bed to help nurses slowly and smoothly transfer overweight patients from medical beds to other locations. Additionally, Takanokura et al. (2016) developed a systemic approach by using sensor devices surrounding the nursing bed to prevent patients from fallings and secondary injures. Besides, Davis et al. (2017) explored how hospital bed design can minimize active and passive patient displacement. The study not only assessed how many migrations occurred immediately after head joint cleanup but also performed additional migration measurements on participants with limited mobility during standard 2-h repositioning. Implications for practice were especially available in intensive care unit beds (Winzelberg et al. 2016).

Regarding user experience of nursing bed, some studies concerned with patient status while in bed. For example, Nakagawa et al. (2017) studied the distribution of patient's body pressure from bed to wheelchair. The study found that the movement created high contact pressure on the patient when seated. Kim et al. (2016) designed a new moving with multiple LINACs to solve the obstacle of high precision treatment concerning respiratory motion. A force distribution method and dynamics of the bed were identified. Rigid body simulation model was made to verify that the bed can operate well as expected. Additionally, Fitch et al. (2016) investigated the hospital bed type and safety height of ordinary hospital bed and intensive care setting. The research team conducted a survey to find out how the nurses measure the optimal angle of head of bed in cardiac surgery intensive care unit. Besides, Weiner et al. (2017) studied on selection of an ergonomic aid to avoid female nurses spinal injury while moving passive patients into beds. To achieve the purpose, a lumbar motion monitor and Borg scale were used. The results proposed the optimal assistive devices for reducing musculoskeletal burden. In the development of nursing beds, Peng et al. (2016) proposed a nursing bed controlled by a hybrid brain–computer interface. The nursing bed involves a steady-state visually evoked potential and a P300 smart nursing bed system. The effectiveness of the system was demonstrated by experimenting with eight healthy subjects. Domestic scholars have established a design and development project for intelligent nursing beds. Also, they realized project organization and management. Furthermore, they achieved a win–win situation through various teaching methods and scientific evaluation methods (Jiang et al. 2017). In summary, there is few research concern emotional feelings that is the rationale to conduct this study with concentration on

applying Kansei Engineering in the design and evaluation of medical nursing bed.

Furthermore, less research on user experience of requirements for new type of smart nursing beds. For instance, Cai et al. (2015) studied on user experience of smart beds at home with concentration on transformation of health care techniques from passive recipient to innovator, individualized care, work flow redesign, and the intrusion of sensor technology on patient's privacy. The data was collected by traditional triangulation including log book, observation ($n = 45$ h), and interviews ($n = 23$). Findings indicated that functions of smart bed enables greater individualized care, redefining workflow, and saving healthcare professionals' time on healthcare for elderly patients. In general, the purpose of designing a smart bed is to help a patient in his or her daily life, facilitate the work of clinical staff, and improve care quality. Besides, Lui et al. (2017) designed and developed the smart bed by using an eye tracker. Disabled patients worked with the help under the non-contact eye tracker that it helped disabled patients communicate with beds for better self-care. Moreover, Jiang et al. summarized the development trend of multifunctional nursing beds toward intelligent detection and recovery. He also proposed four functional categories of multifunctional nursing beds, namely safety protection, treatment assistance, comfortable optimization, and human–computer interaction and communication. Finally, the study proposed four primary functional trends namely physiological parameter monitoring, sleep aid, intelligent temperature control, and video communication by comparing existing functions and potential user requirements. Of course, there are some recent research on user experience, such as Takamatsu et al. (2016) developed meter-scale large-area capacitive fabric pressure sensors for floor sensors to monitor human position. Their meter-scale pressure sensor fabric technology will be used for bed and with meter-scale pressure sensor fabric technology, floor sensors can be applied to monitor for monitoring old people in nursing homes and hospitals which is a good invention for patients. And Zhuang et al. (2018) proposes kind of novel idea of implementing a decision support system (DSS) based on both the prevalent MEAN architecture and the R statistical language platform, helping the end-users of health care systems make better decisions. All these help to solve user experience problems.

Recently, it was not relatively matured and perfect yet for the product designs and evaluation methods of nursing bed. On the one hand, it was difficult for people to separate subjective factors out of the evaluation of the proposal in the process of evaluation on design. It caused a big difference of evaluation and conclusion resulted by different evaluators toward the same design proposal (Caron et al. 2016; Kendler et al. 2008). On the other hand, it was

difficult to quantify the design results. In design evaluation, linguistic conclusions were often obtained, and it was impossible to compare the advantages and disadvantages of each design proposal through data materials and rational means. Therefore, it was a trend to apply the methodology of Kansei Engineering and brain-computer interface fusion in designing the nursing bed. First of all, Zhou developed 6 pairs of perceptual adjectives through six research steps of Kansei Engineering. Secondly, he designed the nursing bed according to the users' sensitive needs. Thirdly, he conducted an empirical research on user experience and found that 40 subjects felt satisfied by the designed nursing bed. Besides, Kittidecha et al. (2018) also explored the relationship between the perceptual demand of human and design characteristics of product. Moreover, some research transformed perceptual demands into morphological elements of design in details through scientific methods. Perceptual design of product was to study the relationship between people and things (Harrington et al. 2003; Kai et al. 2017). It deeply explored the relationship between people's "psychological feelings" and "substantial objects". It helped product designers better understand consumers' demands. It accurately describes the expectations and feelings of product quality. It provided an innovative way to create better quality and appearance of product (Johnson 1996).

Regarding EEG studies, findings have showed that the EEG evaluation method has obvious advantages (Nunez et al. 2017; Ratcliff et al. 2009). For instance, the measure of attention obtained from synchronous EEG recordings could explain for each test evidence accumulation rate and perceptual preprocessing time in visual decision tasks. Additionally, the EEG neurophysiological number of a single test body under the same stimulus can be used to rank behavioral response time and weigh the quality of relevant decision-making evidence. Regarding eye-tracking research, results showed that eye movements could provide new insights for the memory process in decision-making (Scholz et al. 2015). Furthermore, more precise decision-making assumptions could be made according to previous studies on attention of eye movement (Orquin et al. 2013).

The evaluation indicators of automotive industry were determined by user experience of subjective psychological quantity and objective physiological quantity through eye movement and EEG. First of all, users separately evaluated subjective psychological quantity for four car design proposals to obtain the average of the comprehensive evaluation scores each car. Secondly, eye movement and EEG were applied for evaluating objective physiological quantity. On the one hand, evaluation indicators of eye movement experiment were to count the gaze time, the number of gaze, and the hot spot map index were counted. On the

other hand, ERP topographic map was to determine the effective electrode with the P300 induced EEG peak. Thirdly, correlation analysis was conducted between eye movement and EEG. Fourthly, the optimal value and the worst value of evaluation were comprehensively obtained such as psychological and physiological values according to different dimensions of four car design proposals. Fifthly, closeness was analyzed between the optimal and the worst value each design proposal. Finally, ranking table of automobile evaluation was developed according to different electrode position.

This paper takes the medical nursing bed as the research object, combines the product nature of the medical nursing bed, improves and explores the hypothesis of Tang Bang-bei and others, that is, there is a certain correlation between the subjective and the data of eye movement and EEG, and applies it to the research of the design and evaluation method of the medical nursing bed. Firstly, using the theory of Kansei Engineering to carry out product designs, four design proposals were obtained. Then, the evaluation methods and models of nursing beds were studied by means of the users' subjective psychological evaluation which are obtained by Likert scale, eye movement data and EEG data. The ultimately goal was to establish an objective and comprehensive evaluation and verification system. To solve the problem of expert or leader's subjective decision-making and lack of scientific basis in the selection of nursing bed design scheme, and provide objective data support for the subjective evaluation of nursing bed proposals.

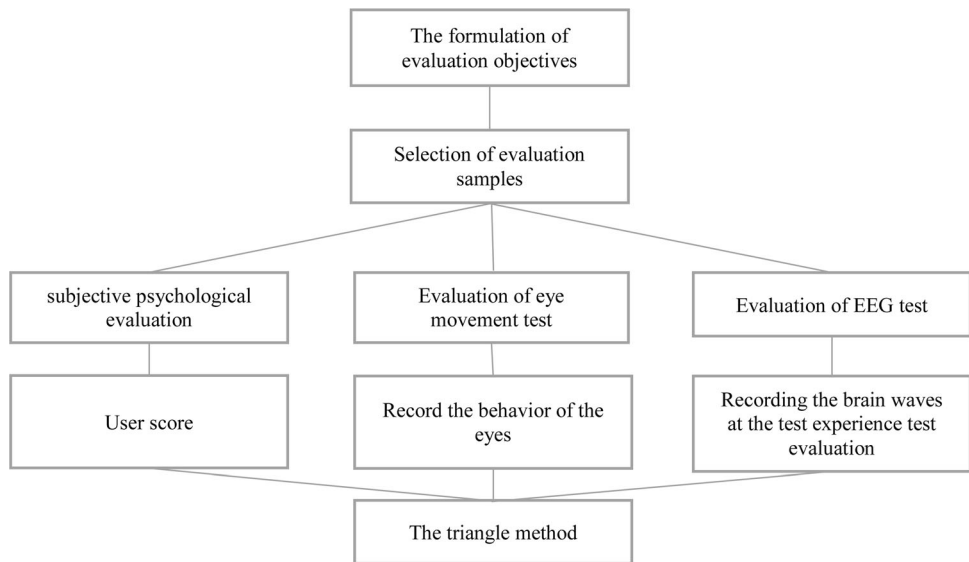
2 The triangle verification model of medical nursing bed

2.1 The triangle verification model based on Kansei Engineering

Based on Kansei Engineering, this paper combines the psychological and physiological data collected from the experiment, i.e. the three dimensions data including subjective evaluation, eye movement and EEG, and establishes a triangular validation evaluation system of nursing bed. The specific execution process is shown in Fig. 1. Firstly, the objective of the evaluation is to determine the proposals of four nursing beds. Subjects are selected to obtain the subjective score, record the eye movement data, and the EEG data. The data are analyzed by the triangle verification model and the conclusion is drawn.

In Fig. 1, firstly, the objective of the evaluation, namely, four nursing bed design proposals, was determined. Participants were selected as subjects. Subjective evaluation were obtained by subjective evaluation, eye movement test

Fig. 1 Flow chart of triangle verification model



evaluation and electroencephalogram test evaluation. Finally, we get the data of this experimental model.

2.2 Selection of experimental materials- medical nursing bed proposals

Kansei Engineering is a kind of design technology which reflects consumers’ emotional demands, psychological tendency and cognitive habits into product development. Researchers based on semantic difference method, studied the perceptual needs of bedridden patients, and transformed them into analysis data, mapping the design elements of nursing beds with perceptual vocabulary, providing a reference for the design of medical nursing beds. In this follow-up study, using the theory of Kansei Engineering, a sample bank of medical nursing beds was established. The users scored the representative products in the sample bank with questionnaires. The results showed that “Energy-saving, Comfortable, Concise, Luxury” had the highest score. Referring to the evaluation results of the sample bank nursing bed, the nursing bed was designed from four imagery directions. In order to keep the same function, the overall design was made according to the different shape of the nursing bed, the bed board and the railings. Finally, four design proposals were obtained. Since the focus of this study is not on the design process, there is no need to repeat it. The four design features are as Table 1:

2.3 Users’ evaluation test of medical nursing beds

Figure 2 showed the evaluation test of medical nursing beds. Firstly, the pictures of nursing beds were presented to the subjects, and the evaluation of the test materials was

recorded with the help of scoring and recording software; the eye tracker was used to obtain the scanning and gazing behavior of the subjects’ eyes; and the EEG data were obtained by the EEG recording system.

2.4 Data processing of users’ evaluation of medical nursing beds

Testing program is $C = \{c_1, c_2, c_3, \dots, c_m\}$; being tested program is $B = \{b_1, b_2, b_3, \dots, b_n\}$. m shows the number of testing program and n means the number of being tested people.

2.4.1 Data processing of users’ subjective evaluation

Subjects in this paper evaluated the proposals of nursing bed subjectively by using the five-level scale of Likert Scale. Finally, the expected value of psychological evaluation of all the subjects on the design of nursing bed was obtained, and the matrix P of psychological evaluation was obtained. The way to get the subjective psychological evaluation data is shown in Fig. 3.





Assuming the subject n ’s evaluation of the proposal m is $p_{n,m}$, the matrix P is constituted by the subjects (b_1, b_2, \dots, b_n) , evaluation scores of the proposals (c_1, c_2, \dots, c_m)

$$P = \begin{bmatrix} p_{1,1} & p_{1,2} & \dots & p_{1,m} \\ p_{2,1} & p_{2,2} & \dots & p_{2,m} \\ \vdots & \vdots & \dots & \vdots \\ p_{n,1} & p_{n,2} & \dots & p_{n,m} \end{bmatrix} \tag{1}$$

Expected value of Subjective evaluation of proposal i should be:

$$p_i = \frac{p_{1,i} + p_{2,i} + \dots + p_{n,i}}{n} \tag{2}$$

Table 1 Comparison table of four design proposals

	Proposal 1	Proposal 2	Proposal 3	Proposal 4	
					
External appearance	Position	Energy-saving	Comfortable	Concise	Luxury
	Shape	With wide margin and large area	Rounded rectangle and line surface combined	trapezoid element and shape of “工”	Complicated shape and concave surface
	Bed board and handrail	The hole of bed board can easily grip and save energy. High handrail can give people security.	Fillet cut-up design. handrail is round and fluent, which make people feel comfortable.	Distinct drawing line with concise feeling	Apply curve and surface numerously. Round shape with variety.

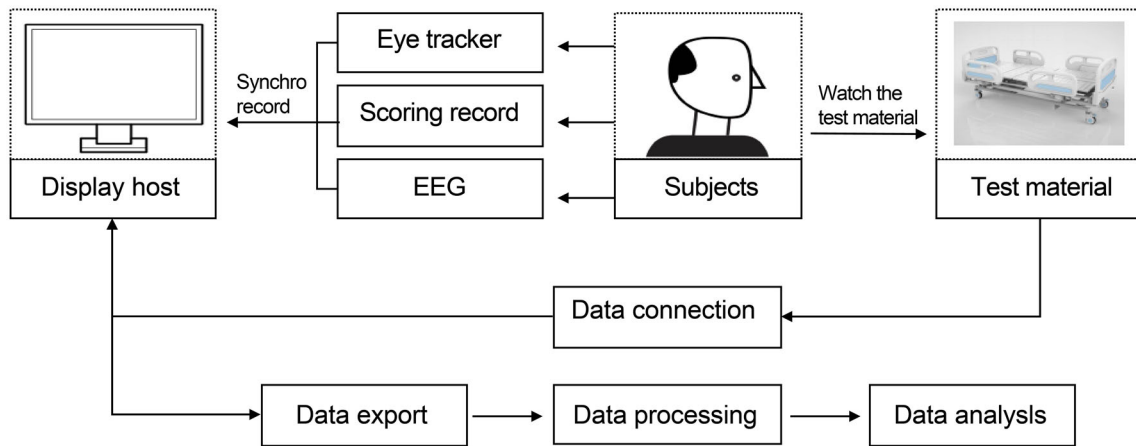
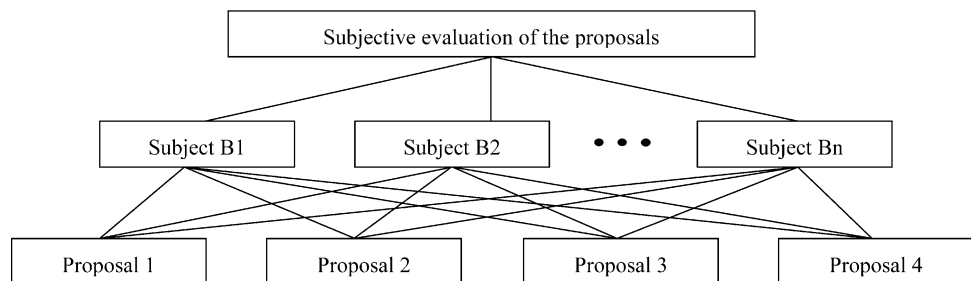


Fig. 2 Users’ evaluation Eest of medical nursing beds

Fig. 3 A schematic diagram of the subjective evaluation process of the subjects



The matrix P should be:

$$P^T = [P_{c_1} P_{c_2} \dots P_{c_n}]$$

2.4.2 Data processing of users’ eye movement

- (3) According to the psychological research, people’s cognition and perception are all evaluative. When people face something or someone, they will evaluate on good, bad,

active or passive aspects. This evaluative message will be displayed through people's physiology and psychology. In this research, we use eye tracker to record eye movement data when tested people are in different medical nursing bed program, and then get the data of eye movement for different proposals. The counterpart for each eye movement testing index will be:

$$Y = \{y_{ij}(e)\}, i = 1, 2, \dots, n; j = 1, 2, \dots, m, \quad (4)$$

$y_{ij}(e)$ means that tested people's each eye movement index b_i for proposal c_j , is a column vector.

The expected value of eye movement for proposal j should be:

$$\bar{y}_j(e) = \frac{y_{1j}(e) + y_{2j}(e) + \dots + y_{nj}(e)}{n}, j = 1, 2, \dots, m. \quad (5)$$

From the formula (5) above, we can see that $\bar{y}_j(e)$ is a column vector, and equals to the expected value of all tested people eye movement.

Calculated all the eye movement index data, we can get matrix E:

$$E^T = [\bar{y}_1(e) \ \bar{y}_2(e) \ \dots \ \bar{y}_m(e)]. \quad (6)$$

In this paper, the eye movement index includes fixation time, the number of fixations and first fixation duration. First fixation duration replaces the traditional hot spot image because first fixation duration can reveal the level of vision attraction for the different medical nursing bed programs wholly. However, the hot spot image can only reflect the concern for the part of the proposal. The matrix E is a $m \times 3$ matrix.

2.4.3 Data processing of users' EEG

By EEG recording system, brainwave data D of tested people's cerebral cortex can be recorded synchronously when they see each proposal, the formula is below:

$$D = \{d_{ij}(g)\}, i = 1, 2, \dots, n; j = 1, 2, \dots, m. \quad (7)$$

In this formula, $d_{ij}(g)$ means the brainwave data of tested people b_i for proposal c_j , it is a column vector. $g = \{g_1, g_2, \dots, g_{32}\}$, g_i means i^{th} brainwave data.

Based on the formula (7), the expected value of brainwave for proposal j should be:

$$\bar{d}_j(G) = \frac{d_{1j}(G) + d_{2j}(G) + \dots + d_{nj}(G)}{n}, j = 1, 2, \dots, m. \quad (8)$$

From formula (8), we can know that $\bar{d}_j(G)$ is a column vector. It means the expected value of all tested people's brainwave data.

Calculated by formula (8), we can get the expected value of m numbers of proposals, and put together into matrix D:

$$D^T = [\bar{d}_1(g) \ \bar{d}_2(g) \ \dots \ \bar{d}_m(g)]. \quad (9)$$

In this paper, matrix D is a matrix.

2.4.4 Integrated evaluation date of medical nursing bed

In order to improve the randomness of subjective evaluation and increase reliability, this paper fuses subjective data, eye movement data and EEG data together and becomes the data source of the triangle test model based on perceptual engineering. By this model, it adds objective data test to subjective evaluation of nursing bed.

Combining the matrix P, matrix E and the matrix D, we get matrix Z:

$$Z = [P, E, D] = \begin{bmatrix} w_1 & \bar{y}_1(e) & \bar{d}_1(g) \\ w_1 & \bar{y}_2(e) & \bar{d}_2(g) \\ \vdots & \vdots & \vdots \\ w_m & \bar{y}_m(e) & \bar{d}_m(g) \end{bmatrix}, \quad (10)$$

Z is a $m \times 15$ matrix, an integrated value of each evaluation level when people experience product proposals of medical nursing equipment.

3 Acquisition of experimental data

In order to verify the availability of the triangle test, we conduct an experiment combined subjective evaluation, eye movement test and EEG for medical nursing beds. The whole experiment constituted of tested people, experimental equipment, experimental material and experimental process.

3.1 Research participant

Totally twenty-four people who were normal in vision, but four people didn't collect brainwave signal since due to over head-shaking. Finally, there are twenty valid participants, including eleven men and nine women. Their average age is 22.84. Specific information is as Table 2.

3.2 Experimental equipment

In this experiment, Tobii X3-120, a small Eye Movement Instrument made by Sweden Tobii Company, is used. The accuracy is 0.2 degrees, and the sampling rate is 120 Hz. It can provide portability and large head movement range, and ensure high quality tracking accuracy and stable tracking ability.

Table 2 Personal information table of participants

	Gender		Age(years)			Career		
	Men	Women	18–25	26–35	36–45	Student	Teacher	Worker
No.	11	9	14	5	1	15	4	1

The EEG signal acquisition instrument used in the experiment is NeurOne Innovative Research System produced by Mega Electronics, USA. It has 24-bit analog-to-digital conversion, sensitivity is 51 nV/bit, input range is (+430 mV), 40-channel amplifier includes 32 EEG + 8 bipolar channels. This neuroscience measurement system will provide a more accurate, cleaner signal, faster sampling, modular solutions and use of the latest processing in digital signal processing, more flexibility and scalability.

3.3 Experimental material

The guiding words for this experiment are:

Hello! Welcome to participate in this evaluation experience experiment, the experiment will first present a “ + ” sign, after the “ + ” there will appear pictures, when you see the picture, please as soon as possible evaluate the feelings of this picture between 1 and 5 points, and make the corresponding key reaction, which is 1—”very bad”, 2—”poor”, 3—”general”, 4—”better”, 5—”very good”, if you have understood, please press”P”to start the experiment.

3.4 Experimental process

The definite sequence of experiment as below:

1. Participants use shampoo to wash their hair and then dry it.
2. Participants watch and try to understand the experimental guidance.
3. Researchers prepare brainwave experimental equipment and conduct eye movement experiment
4. Researchers explain experimental process to participants.
5. With the start of formal experiment, participants watch the first effect drawing of medical nursing beds, and score by pressing the button from 1 to 5 (1-worst; 2-worse; 3-normal; 4-better; 5- best). When participants press the button, the first effect drawing experiment ends, the second one starts until all the experimental materials are finished. In order to make sure the validity of experiment, after the first-round of score, four effect drawings will continue to play fifty times randomly.
6. Experiments finished, eye tracker and brain instrument stop recording.

The experimental pictures are shown in Fig. 4. The upper left corner is a picture of the participants washing their hair, the upper right corner is a picture of the



Fig. 4 Experimental pictures

participants wearing experimental measuring equipment, the lower left corner is a picture of the participants explained the experiment, and the lower right corner is a picture of the experiment process.

4 Experimental data processing

4.1 Process of subjective evaluation date

According to experimental outcome and the Likert scale method, we can get the expected value of subjective evaluation of four nursing bed proposals from participants $P^T = [3.65 \ 3.76 \ 3.07 \ 3.45]$, specific as shown in Table 3.

4.2 Process of eye movement data

The data from this eye movement experiment constitute fixation time, the number of fixations and First fixation duration.

4.2.1 Fixation time e1

Fixation time means the time when participants see the effect drawing of medical nursing bed until they make decision. The expected value of gazing time of four nursing bed proposals, as Table 4.

4.2.2 The number of fixations e2

The number of fixations means the times of gaze within the time before participants made the decision after watching

the effective drawing of medical nursing bed. The expected value of the time of gazing of participants for medical nursing bed proposals, as Table 5.

4.2.3 First fixation duration e3

First fixation duration means the moment when participants' eyes catch the effect drawing. The expected value of first fixation duration of participants for medical nursing bed proposals, as Table 6.

Put eye movement data of 4.2.1–4.2.3 above into formula (6), then we can get the matrix E of eye

$$E = \begin{bmatrix} 1.86 & 6.69 & 1.28 \\ 2 & 7.88 & 1.21 \\ 1.75 & 6.33 & 1.54 \\ 1.85 & 6.11 & 1.37 \end{bmatrix},$$

movement data from m proposals.

4.3 Process of brainwave date

4.3.1 Dealing with brainwave date

The original signals that this research collects included autonomous brainwave signals, triggered brainwave signals, and other physical interference signals. Autonomous brainwave signals mean the electric potential of cranial nerves change autonomously without especially external trigger, such as vision, sense of hearing and touch. Triggered brainwave signals mean the electric potential of cranial nerves when sense organ is pressured stimulation. Other physical interference signals include electrooculography, electrocardiogram and electromyogram. Triggered

Table 3 The expected value of subjective evaluation of four proposals

Effect drawing	Proposal 1	Proposal 2	Proposal 3	Proposal 4
The expected value of subjective evaluation	3.65	3.76	3.07	3.45

Table 4 The expected value of fixation time

Effect drawing	Proposal 1	Proposal 2	Proposal 3	Proposal 4
The expected value of Fixation time/s	1.86	2	1.75	1.85

Table 5 The expected value of the number of fixations

Effective drawing	Proposal 1	Proposal 2	Proposal 3	Proposal 4
The expected value of the number of fixations	6.69	7.88	6.33	6.11

Table 6 The expected value of first fixation duration

Effective drawing	Proposal 1	Proposal 2	Proposal 3	Proposal 4
The expected value of First fixation duration/s	1.28	1.21	1.54	1.37

brainwave signals include evaluation message of esthetics experience, so in this research, we conducted refinement and analysis of triggered brainwave signals. In this experiment, there are twenty-four participants. There are four people didn't collect brainwave signals due to over head-shaking. Finally, there are twenty valid experimental data. Brainwave-collected equipment, respectively collected the brainwave signals of each participants for four proposals by using 32 electrodes. In MATLAB environment, we conducted refinement of triggered brainwave signals for 32 electrodes by applying EEGLAB analysis software. The definite procedure is as below.

Procedure 1, Removing physical interference signals. Triggered brainwave signals have less amplitude and higher keen sensibility. Electrooculography, electrocardiogram and electromyogram will interfere the actual brainwave signals. Therefore, firstly we need to remove the interference signals, such as Electrooculography, electrocardiogram and electromyogram.

Procedure 2, Segmenting brainwave data. Triggered brainwave signals was occurred after receiving stimulation, so when we refined triggered brainwave signals, we just needed to process this signal segment. In this experiment, we collected many times brainwave signals, and formed oscillogram of brainwave. Then we selected valid data segment of oscillogram, and removed the invalid segment of oscillogram. Finally, forming 32 lead 200–800 ms brainwave oscillogram as Fig. 5 and getting 32 lead 200–800 ms brainwave oscillogram of twenty-three participants for four different proposals.

Procedure 3. Digital filter. Brainwave signals belong low-frequency signals, which are easily interfered by other high-frequency noise signals. By the digital filter of

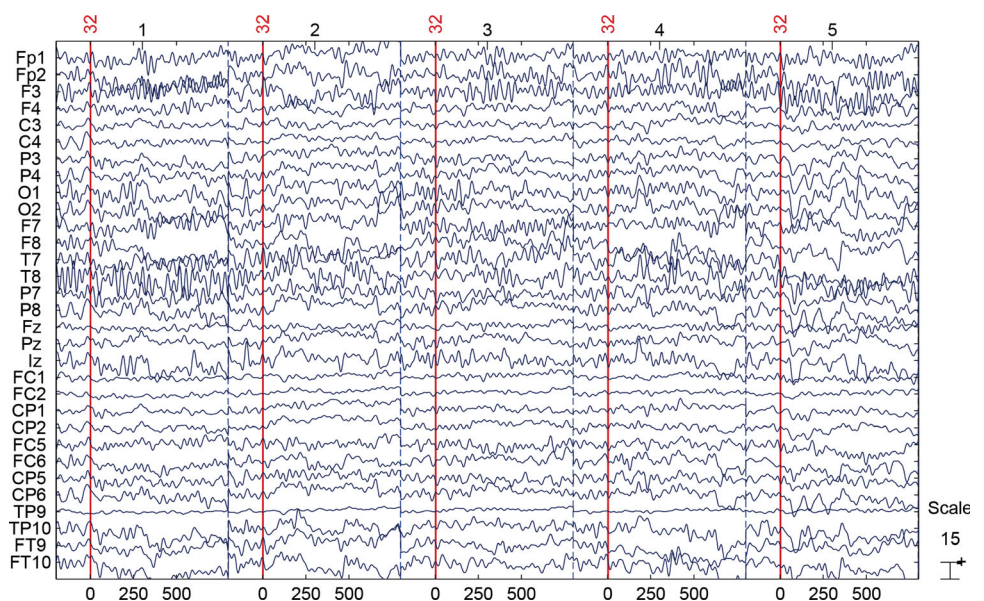
EEGLAB software, we can conduct 20 Hz digital filter process for processed brainwave oscillogram and remove interfering signals.

Procedure 4. Superimposed average of amplitude. The amplitude of autonomous brainwave signals is between dozens and hundreds of microvolts. The highest signal of triggered brainwave is only 10uV. Triggered brainwave signals will be covered by autonomous brainwave signals, so we cannot observe it directly. Through average amplitude, the brainwave signals of counterpart experimental material for all participants can be superimposed. Autonomous brainwave signal is random signal, so the superimposed average is 0. Triggered brainwave signal is certain signal, so the superimposed average maintains the same basically. Through average amplitude, we can refine triggered brainwave signals. Firstly, we needed to get several brainwave amplitude segments for four programs of the same participants, then conduct superimposition. After superimposed average, we would get the amplitude as Fig. 6, a thirty-two superimposed average electrode brainwave amplitude of one participant after this participant observed one program for many times.

4.3.2 Triggered brainwave topography analysis

By making use of independent composition analysis (ICA) of EEGLAB brainwave data processing software, we can conduct independent composition analysis of processed brainwave data, and draw all the participants' thirty-two electrode data into brainwave topography. Through analysis, to filter the most representative brainwave topography, and observe the energy scatter of brainwave under each effect drawing more directly. The darker the color is,

Fig. 5 32 Lead 200 ~ 800 ms brainwave oscillogram



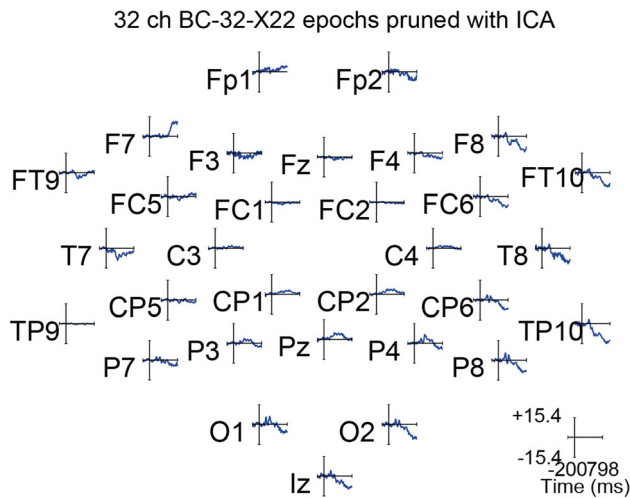


Fig. 6 Superimposed average amplitude

the more average energy that Event-Related Potentials (ERP) has. Under the trigger of the same design effect drawing, the participants are triggered brainwave topography under -200 – 800 ms different programs, as picture 7. Compared with brainwave topography, we found that being triggered by programs, the active area of cerebrum (red and orange area in electroencephalography) would focus on Frontal Lobe, which are mainly in charge of consciousness and thinking functions. Compared with electrode scatter picture showed in Fig. 7, we found that frontal lobe includes eleven electrodes, such as F3, F4, F7, F8, Fz, FC1, FC2, FC5, FC6, FT9, FT10.

4.3.3 Triggered brainwave amplitude analysis

Through MATLAB, we can conduct superimposed average amplitude of the same electrode brainwave signals from one program of twenty participants, and finally get the different triggered brainwave data of thirty-two brainwave electrode from four proposals. From brainwave topography, the active area of cerebrum are certainly the eleven electrodes used for the sense of beauty (Medina et al. 2013), including F3, F4, F7, F8, Fz, FC1, FC2, FC5, FC6, FT9, FT10. By making use of MATLAB, we can draw the brainwave amplitude for four different programs of each electrode, and superimpose the average of the same

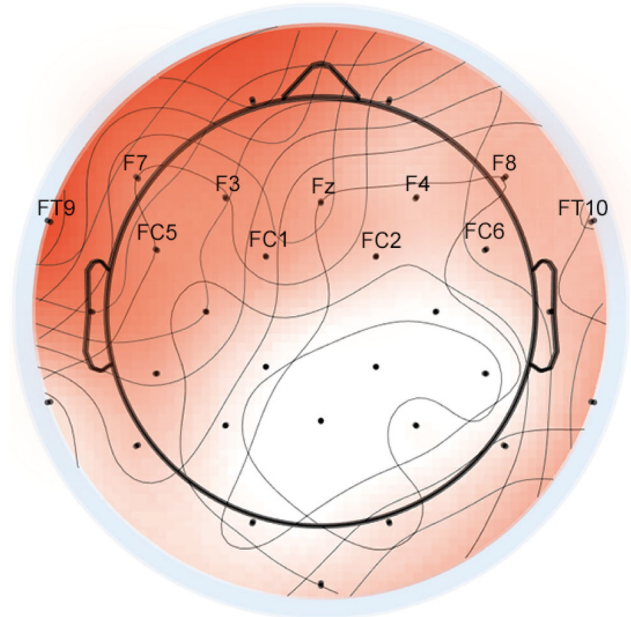


Fig. 7 Electrode brainwave topography

electrode amplitude from different participants in the same program.

With plot function, we can draw the amplitude of each electrode for four programs, Typical amplitude is shown in Fig. 8.

Abscissa means “time” with unit “ms” and based on the study of event related potential P300, we record -200 – 800 ms brainwave signals. Ordinate means “amplitude” with unit “ μV ”. The amplitude of brainwave signals changes within -10 – 10 μV . By analyzing triggered brainwave contrast picture, we found that when participants conduct the sense of beauty experiment for four different proposals, the peak value of triggered brainwave is also different. Through the comprehensive analysis of the pictures, we found that the peak value of EEG induced by the proposal appeared between 250 and 350 ms, as shown in Fig. 8, the peak value of 2.11 μV appeared between 280 and 310 ms in proposal 2. In MATLAB, the data from 250 to 350 ms were intercepted and the peak value of EEG amplitude at 250 to 350 ms was obtained by searching for the maximum value. Then we got the matrix D, the specific data is shown in Table 7.

$$D = \begin{bmatrix} 2.46 & 2.9 & 2.67 & 3.56 & 2.45 & 4.11 & 1.74 & 3.15 & 1.67 & 6.04 & 3.97 \\ 3.08 & 2.97 & 3.1 & 4.09 & 3.43 & 4.76 & 1.99 & 3.31 & 2.11 & 6.32 & 4.94 \\ 1.69 & 2.64 & 2.37 & 2.63 & 2.27 & 3.76 & 1.39 & 2.48 & 1.39 & 5.4 & 3.31 \\ 2.01 & 2.74 & 2.51 & 3.01 & 2.55 & 3.73 & 1.36 & 2.43 & 1.61 & 5.47 & 3.49 \end{bmatrix}$$

Fig. 8 Proposals in triggered brainwave contrast picture of FT9 electrodes

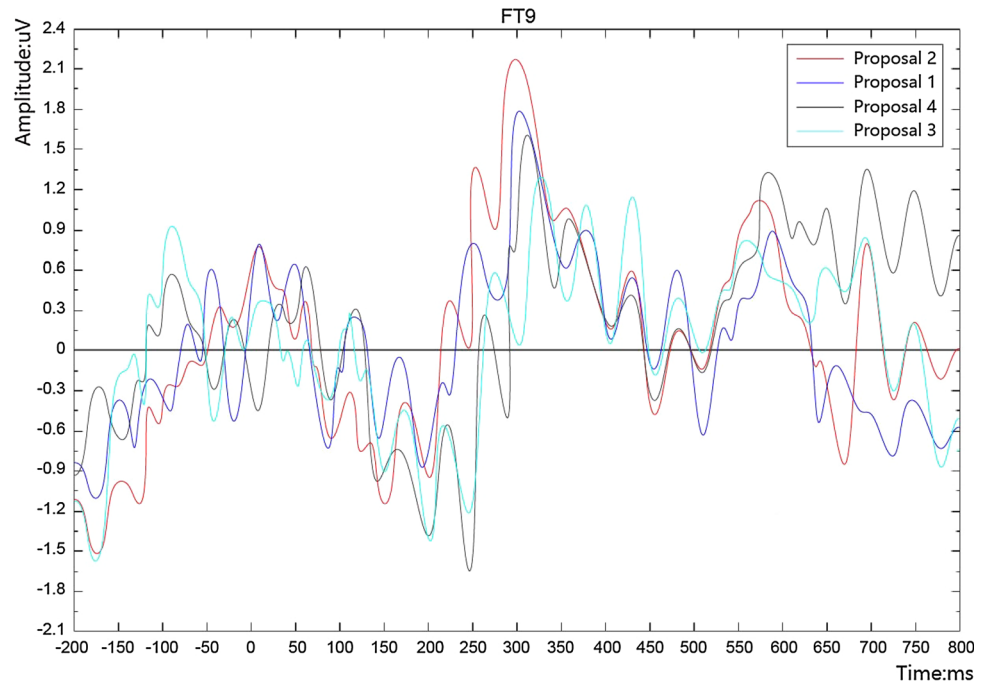


Table 7 The peak value of triggered brainwave in different electrodes for four proposals

Triggered electrodes	Medical nursing bed programs			
	Proposal 1	Proposal 2	Proposal 3	Proposal 4
F4	2.46	3.08	1.69	2.01
F7	2.9	2.97	2.64	2.74
F8	2.67	3.1	2.37	2.51
FZ	3.56	4.09	2.63	3.01
FC1	2.45	3.43	2.27	2.55
FC2	4.11	4.76	3.76	3.73
FC5	1.74	1.99	1.39	1.36
FC6	3.15	3.31	2.48	2.43
FT9	1.67	2.11	1.39	1.61
FT10	6.04	6.32	5.4	5.47
F3	3.97	4.94	3.31	3.49

4.4 Fusion evaluation model data

Putting all the evaluation index above, including subjective evaluation P, integrated value of eye movement E and integrated value of brainwave D into the following formula, and getting the integrated evaluation data Z:

The vectors in matrix Z, is the data of four design proposals of nursing beds on 15 evaluation index, which are subjective evaluation data P, fixation time e1, the number of fixations e2, first fixation time e3, and electrode F4, F7, F8, FZ, FC1, FC2, FC5, FC6, FT9, FT10, F3.

$$Z = [P, E, D] = [Z_{ij}]_{4 \times 15} = \begin{bmatrix} 3.65 & 1.86 & 6.69 & 1.28 & 2.46 & 2.9 & 2.67 & 3.56 & 2.45 & 4.11 & 1.74 & 3.15 & 1.67 & 6.04 & 3.97 \\ 3.76 & 2 & 7.88 & 1.21 & 3.08 & 2.97 & 3.1 & 4.09 & 3.43 & 4.76 & 1.99 & 3.31 & 2.11 & 6.32 & 4.94 \\ 3.07 & 1.75 & 6.33 & 1.54 & 1.69 & 2.64 & 2.37 & 2.63 & 2.27 & 3.76 & 1.39 & 2.48 & 1.39 & 5.4 & 3.31 \\ 3.45 & 1.85 & 6.11 & 1.37 & 2.01 & 2.74 & 2.51 & 3.01 & 2.55 & 3.73 & 1.36 & 2.43 & 1.61 & 5.47 & 3.49 \end{bmatrix}$$

5 Data analysis

5.1 Verify the relevance and saliency of data

In order to verify the hypothesis that subjective evaluation, eye movement data and EEG data have a certain relationship, correlation analysis and significance analysis are needed. Correlation analysis is a statistical analysis method by studying the correlation between two or more random variables in the same position. Significance mainly proves the reliability of the correlation coefficient. This analysis focuses on discovering the correlation properties among random variables. The degree of correlation between the two variables is expressed by the correlation coefficient R . The value of the correlation coefficient R is between -1 and 1. In positive correlation, the R value is between 0 and 1, one variable increases, the other variable also increases; in negative correlation, the R value is between -1 and 0, when one variable increases, the other variable will decrease. The closer the absolute value of R to 1, the stronger the correlation between the two variables, the closer the absolute value of R to 0, the weaker the correlation between the two variables. According to the absolute value of correlation R , the following distinctions can be made: 0–0.33 is weak correlation, 0.33–0.67 is medium correlation, and 0.67–1 is strong correlation. In this paper, correlation coefficients were used to analyze the correlation between the subjective evaluation P , fixation time $e1$, the number of fixations $e2$, first fixation time $e3$ and the peak values of $F4$, $F7$, $F8$, FZ , $FC1$, $FC2$, $FC5$, $FC6$, $FT9$, $FT10$ and $F3$ of the four proposals. The specific correlation coefficient is shown in Table 8.

In Table 8, the data with ** indicates significance at 0.01 level, and the correlation is very significant, * indicates significance at 0.05 level, and the correlation is significant. There are 105 data in the table (a total of 15 index, correlation and significance validation between the two, $C_{15}^2 = 105$), among them, 68 data have reached the saliency requirement, and the saliency rate is 64.76%. This shows that most of the relevant data are reliable. Table 8 shows that the absolute value of the correlation coefficient r between all the indicators is greater than 0.66, indicating that there is a strong correlation between the evaluation indicators. The $e3$ (First fixation time) was negatively correlated with other data. The shorter the first fixation time, the more interested the subjects were, so the data was negatively correlated with other data. From the analysis, we can see that the hypothesis that subjective evaluation, eye movement data and EEG data have a certain relationship is verified.

5.2 Analysis of relative closeness

Relative closeness is the relative level to measure the maximum distance of data. In order to make the holistic evaluation for four design proposals, the index on different fundamental units has comparability. Under different physical and psychological dimensions, we needed to conduct relative closeness analysis for integrated data Z to analyze pros and cons of each design proposals. To normalize the index of data Z , the following are to conduct relative closeness analysis under each dimension. The definite procedures are as followed:

Procedure 1. To calculate the maximum F_{ij}^+ and minimum F_{ij}^- of each evaluation index

$$F_{ij}^+ = \max\{Z_{ij}\}, i = 1, 2, \dots, 15; j = 1, 2, 3, 4, \quad (11)$$

$$F_{ij}^- = \min\{Z_{ij}\}, i = 1, 2, \dots, 15; j = 1, 2, 3, 4. \quad (12)$$

In formula, Z_{ij} is the value of i design proposal under j evaluation dimension, and then put the integrated evaluation outcome into (11) and (12) formula, respectively, as Table 9. In the table, the bold faced letters mean the maximum and minimum of evaluation indexes.

Procedure 2. To calculate the distance from the maximum to minimum of each proposal

The formula to calculate the distance from the maximum to minimum of each proposal as below

$$d_{ij}^+ = F_{ij}^+ - Z_{ij} \quad (13)$$

$$d_{ij}^- = Z_{ij} - F_{ij}^-. \quad (14)$$

In formula, d_{ij}^+ is the maximum distance of i index in j proposal; d_{ij}^- is the minimum distance of i index in j proposal. $i = 1, 2, \dots, 15$ and $j = 1, 2, 3, 4$. Putting the integrated data into formula (13) and (14) can get Table 10 as below.

Procedure 3. To calculate relative closeness of evaluative value and maximum for each program.

We use the relative closeness of evaluative value and maximum for each proposal, as the foundation of final evaluation for the design proposal.

$$Z'_{ij} = \frac{d_{ij}^-}{d_{ij}^- + d_{ij}^+}. \quad (15)$$

In formula, $Z'_{ij} \in [0, 1], i = 1, 2, \dots, 15; j = 1, 2, 3, 4$. Putting the data above into the formula (15) can get the relative closeness of evaluative value and maximum for each proposal, as Table 11.

According to Table 11, after analyzing relative closeness, all the evaluation indexes are normalized to the range $[0, 1]$ which are more easily to make comparison. For example, in index $e1$, proposal $C2$ got the highest scores and participants have the best user experience among four

Table 8 The related coefficients among subjective evaluation, eye movement and Brainwave Index

P	e1	e2	e3	F4	F7	F8	FZ	FC1	FC2	FC5	FC6	FT9	FT10	F3
P	1	0.903*	0.693	-0.998**	0.919*	0.966*	0.862	0.944*	0.773	0.825	0.835	0.872	0.887	0.838
e1	0.903*	1	0.866	-0.926*	0.963*	0.903*	0.973*	0.949*	0.905*	0.859	0.784	0.994**	0.872	0.951*
e2	0.693	0.866	1	-0.731	0.921*	0.822	0.954*	0.89	0.993**	0.946*	0.865	0.915*	0.902*	0.973*
e3	-0.998**	-0.926*	-0.731	1	-0.939*	-0.973*	-0.89	-0.959*	-0.806	-0.847	-0.847	-0.899	-0.903*	-0.867
F4	0.919*	0.963*	0.921*	-0.939*	1	0.970*	0.988**	0.996**	0.960*	0.962*	0.922*	0.972*	0.971*	0.985**
F7	0.966*	0.903*	0.822	-0.973*	0.970*	1	0.921*	0.988**	0.883	0.940*	0.948*	0.898	0.976*	0.917*
F8	0.862	0.973*	0.954*	-0.89	0.988**	0.921*	1	0.970*	0.979*	0.944*	0.875	0.990**	0.937*	0.996**
FZ	0.944*	0.949*	0.89	-0.959*	0.996**	0.988**	0.970*	1	0.938*	0.959*	0.936*	0.952*	0.979*	0.966*
FC1	0.729	0.951*	0.914*	-0.767	0.895	0.767	0.951*	0.855	0.917*	0.81	0.687	0.969*	0.784	0.937*
FC2	0.773	0.905*	0.993**	-0.806	0.960*	0.883	0.979*	0.938*	1	0.971*	0.904*	0.943*	0.943*	0.992**
FC5	0.825	0.859	0.946*	-0.847	0.962*	0.940*	0.944*	0.81	0.971*	1	0.980*	0.891	0.991**	0.964*
FC6	0.835	0.784	0.865	-0.847	0.922*	0.948*	0.875	0.687	0.904*	0.980*	1	0.81	0.987**	0.898
FT9	0.872	0.994**	0.915*	-0.899	0.972*	0.898	0.990**	0.969*	0.943*	0.891	0.81	1	0.891	0.975*
FT10	0.887	0.872	0.902*	-0.903*	0.971*	0.976*	0.937*	0.784	0.943*	0.991**	0.987**	0.891	1	0.950*
F3	0.838	0.951*	0.973*	-0.867	0.985**	0.917*	0.996**	0.937*	0.992**	0.964*	0.898	0.975*	0.950*	1

**At the 0.01 level, the correlation is significant

*At the 0.05 level, the correlation was significant

Table 9 The maximum and minimum of each design proposal under different dimension

Dimension index	Design proposals				Maximum	Minimum
	C1	C2	C3	C4		
P	3.65	3.76	3.07	3.45	3.76	3.07
e1	1.86	2	1.75	1.85	2	1.75
e2	6.69	7.88	6.33	6.11	7.88	6.11
e3	1.28	1.21	1.54	1.37	1.54	1.21
F4	2.46	3.08	1.69	2.01	3.08	1.69
F7	2.9	2.97	2.64	2.74	2.97	2.64
F8	2.67	3.1	2.37	2.51	3.1	2.37
FZ	3.56	4.09	2.63	3.01	4.09	2.63
FC1	2.45	3.43	2.27	2.55	3.43	2.27
FC2	4.11	4.76	3.76	3.73	4.76	3.73
FC5	1.74	1.99	1.39	1.36	1.99	1.36
FC6	3.15	3.31	2.48	2.43	3.31	2.43
FT9	1.67	2.11	1.39	1.61	2.11	1.39
FT10	6.04	6.32	5.4	5.47	6.32	5.4
F3	3.97	4.94	3.31	3.49	4.94	3.31

Table 10 The distance from the maximum to minimum of each proposal

Dimension	d_{ij}^+				d_{ij}^-			
	C1	C2	C3	C4	C1	C2	C3	C4
P	0.11	0	0.69	0.31	0.58	0.69	0	0.38
e1	0.14	0	0.25	0.15	0.11	0.25	0	0.1
e2	1.19	0	1.55	1.77	0.58	1.77	0.22	0
e3	0.26	0.33	0	0.17	0.07	0	0.33	0.16
F4	0.62	0	1.39	1.07	0.77	1.39	0	0.32
F7	0.07	0	0.33	0.23	0.26	0.33	0	0.1
F8	0.43	0	0.73	0.59	0.3	0.73	0	0.14
FZ	0.53	0	1.46	1.08	0.93	1.46	0	0.38
FC1	0.98	0	1.16	0.88	0.18	1.16	0	0.28
FC2	0.65	0	1	1.03	0.38	1.03	0.03	0
FC5	0.25	0	0.6	0.63	0.38	0.63	0.03	0
FC6	0.16	0	0.83	0.88	0.72	0.88	0.05	0
FT9	0.44	0	0.72	0.5	0.28	0.72	0	0.22
FT10	0.28	0	0.92	0.85	0.64	0.92	0	0.07
F3	0.97	0	1.63	1.45	0.66	1.63	0	0.18

proposals. The sorting of four proposals is $C2 > C1 > C4 > C3$.

In this paper, we will use frequency statistics method on three dimensions and 15 evaluation indexes respectively, and get the final ranking method according to the frequency of the four rankings. The specific calculation formula is as follows:

Table 11 The relative closeness and sort table of evaluative value and maximum

Index	Design proposal				Proposal sorting
	C1	C2	C3	C4	
P	0.84	1.00	0.00	0.55	$C2 > C1 > C4 > C3$
e1	0.44	1.00	0.00	0.40	$C2 > C1 > C4 > C3$
e2	0.33	1.00	0.12	0.00	$C2 > C1 > C3 > C4$
e3	0.21	0.00	1.00	0.48	$C2 > C1 > C4 > C3^*$
F4	0.55	1.00	0.00	0.23	$C2 > C1 > C4 > C3$
F7	0.79	1.00	0.00	0.30	$C2 > C1 > C4 > C3$
F8	0.41	1.00	0.00	0.19	$C2 > C1 > C4 > C3$
FZ	0.64	1.00	0.00	0.26	$C2 > C1 > C4 > C3$
FC1	0.16	1.00	0.00	0.24	$C2 > C4 > C1 > C3$
FC2	0.37	1.00	0.03	0.00	$C2 > C1 > C3 > C4$
FC5	0.60	1.00	0.05	0.00	$C2 > C1 > C3 > C4$
FC6	0.82	1.00	0.06	0.00	$C2 > C1 > C3 > C4$
FT9	0.39	1.00	0.00	0.31	$C2 > C1 > C4 > C3$
FT10	0.70	1.00	0.00	0.08	$C2 > C1 > C4 > C3$
F3	0.40	1.00	0.00	0.11	$C2 > C1 > C4 > C3$

$$f_{ip} = \frac{R_{ip}}{Z_b}. \tag{15}$$

Among them, the frequency of the i th proposal appearing in the P ranking is the number of effective evaluation index in different dimensions. In this paper, in the subjective evaluation dimension $Z_b = 1$, in eye movement evaluation dimension $Z_b = 3$, in EEG evaluation dimension $Z_b = 11$, f_{ip} is the frequency of the i th proposal appearing in the P ranking. The specific frequency of the four proposals under different dimensions and ranking is shown in Table 12:

From the proposal ranking in Table 12 we can see that the proposal ranking is $C2 > C1 > C4 > C3$ from the subjective evaluation; from the eye movement evaluation, proposal C2 appears three times in the first place, the highest frequency, so proposal C2 ranks first, proposal C1 appears three times in the second place, the highest frequency, so proposal C1 ranks second, proposal C4 appears in the third place. Two times, the highest frequency, so proposal C4 ranked third, proposal C1 appeared in the first three times, the highest frequency, so proposal C3 ranked second, proposal C3 appeared in the fourth two times, the highest frequency, so proposal C3 ranked fourth, that is, from the eye momentum value, the proposal ranked $C2 > C1 > C4 > C3$; similarly, from the EEG evaluation Look, the ranking is $C2 > C1 > C4 > C3$. From this analysis, we can see that from the three dimensions which are subjective valuation, eye movement objective date, EEG objective date to evaluate the four proposals, the final three dimensions of mutual validation, triangular validation

Table 12 The frequency table of four proposals under different dimension

Subjective evaluation proposals ranking	First place		Second place		Third place		Fourth place	
	R_{ip}	f_{ip}	R_{ip}	f_{ip}	R_{ip}	f_{ip}	R_{ip}	f_{ip}
The frequency table of subjective evaluation								
C1	0	0.00%	1	100.00%	0	0.00%	0	0.00%
C2	1	100.00%	0	0.00%	0	0.00%	0	0.00%
C3	0	0.00%	0	0.00%	0	0.00%	1	100.00%
C4	0	0.00%	0	0.00%	1	100.00%	0	0.00%
Final ranking	C2		C1		C4		C3	
Evaluation of eye movement test proposals ranking	First place		Second place		Third place		Fourth place	
	R_{ip}	f_{ip}	R_{ip}	f_{ip}	R_{ip}	f_{ip}	R_{ip}	f_{ip}
The frequency table of eye movement test evaluation								
C1	0	0.00%	3	100.00%	0	0.00%	0	0.00%
C2	3	100.00%	0	0.00%	0	0.00%	0	0.00%
C3	0	0.00%	0	0.00%	1	33.33%	2	66.67%
C4	0	0.00%	0	0.00%	2	66.67%	1	33.33%
Final ranking	C2		C1		C4		C3	
Evaluation of EEG test proposals ranking	First place		Second place		Third place		Fourth place	
	R_{ip}	f_{ip}	R_{ip}	f_{ip}	R_{ip}	f_{ip}	R_{ip}	f_{ip}
The frequency table of EEG test evaluation								
C1	0	0.00%	10	90.91%	1	9.09%	0	0.00%
C2	11	100.00%	0	0.00%	0	0.00%	0	0.00%
C3	0	0.00%	0	0.00%	3	27.27%	8	72.73%
C4	0	0.00%	1	9.09%	7	63.64%	3	27.27%
Final ranking	C2		C1		C4		C3	

was passed, indicating that the experimental subject evaluation is highly reliable.

6 Conclusion

Based on the research of “User Experience Evaluation of Automobile Industrial Design by Joint Eye Movements and EEG” and considering the psychological and physiological feelings of users in the process of design experience, this paper puts forward a kind of method fusion with subjective evaluation, eye movement and EEG data for the of verifying user subjective evaluation.

Based on the research of Tang Bangbei and others, the following three innovations were carried out in this paper: 1. Eye movement experiment replaced the traditional hotspot map with the first fixation duration. The data of the first fixation duration can reflect the speed of the subjects capturing the visual information of different design proposals of nursing beds, and the data is more accurate and

reliable. However, the hotspot map can only reflect the attention of all the participants in different interest zones of nursing beds, and the results are vague and not convincing; 2. EEG experiment in the end according to the frequency of each proposal in different dimensions and rankings, obtained the priority of the specific nursing beds proposal and passed the model test. The reliability of the subjective evaluation was verified, and the evaluation indexes of the model were put forward, which are subjective evaluation P, fixation time e1, the number of fixations e2, first fixation time e3, EEG electrode F3, F4, F7, F8, FZ, FC1, FC2, FC5, FC6, FT9 and FT10, respectively.

Through the experimental study on user experience evaluation of industrial design of nursing beds, it is proved that this method can effectively provide reliability analysis for traditional subjective design evaluation methods, and more effectively realize relatively objective design proposal selection. The experimental results show that there is a strong positive correlation between the subjective psychological value, eye movement and EEG of user

experience evaluation in industrial design of nursing beds, which provides a more abundant evaluation index for user experience evaluation of industrial design of nursing beds. At the same time, this method has a certain applicability and can be used in the future. The subjective selection of design alternatives in other industrial products design provides a method of judging credibility.

Due to the complexity of the data obtained in this experiment, the experimental data is limited, the experimental results may have some errors. the next step will consider adding more data and probability theory knowledge, in order to do the further study.

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Compliance with ethical standards

Conflict of interest We declare that we have no conflict of interest. We declare that we have no conflict of interest.

Research involving human participants and/or animals All procedures implemented in studies involving human participants conform to the ethical standards of institutions and national research committees, as well as the 1964 Helsinki Declaration and its subsequent amendments or similar ethical standards. All procedures implemented in studies involving human participants conform to the ethical standards of institutions and national research committees, as well as the 1964 Helsinki Declaration and its subsequent amendments or similar ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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