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# Relevance of Emotional Conflict and Gender Differences in the Cognitive Tasks of Digital Interface Layouts Using NIRS Technology

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**ABSTRACT** This article aimed to explore whether there are emotional conflicts and gender differences in the cognitive processing of user interface layouts. By taking the basic layout framework of a shopping interface as the research object and using behavioral experiments and NIRS (Near-Infrared Spectroscopy) technology, this study evaluated the emotional conflict response of men and women to 9 interface layouts formed by the combination of different numbers of layout elements. The results showed that there is a gender difference ($p < 0.05$) in cognition of the interface layout with combinations of 3 and 4 layout elements in the behavioral experiment. Behavioral response was positively correlated with brain function. Oriented by positive emotions, the HbO (oxygenated hemoglobin in the brain) concentration in the cerebral cortex is significantly activated ($p < 0.05$) with gender differences in the case of interfaces combining four elements in the H-type layout frame and three elements in the left-I-type layout frame. These research conclusions can be extended to the application of personalized design and evaluation process of the interface and provide a reference for style changes to digital interface products in actual projects.

**INDEX TERMS** Interface layout, NIRS, behavioral response, emotional conflict, gender differences.

## I. INTRODUCTION

With the rapid development of modern computer and Internet technology, digital interfaces have been widely used as the carrier and medium of Internet communication, which includes web interfaces, software interfaces, mobile device interfaces, multimedia interfaces, etc. The latest "2020 Global Digital Overview" [1] released by We Are Social and Hootsuite shows that digital, mobile and social media have become an indispensable part of people's daily lives all over the world. Currently, more than 4.5 billion people around the world use the Internet, nearly 60%, an increase of 7% compared to January 2019 (298 million new users). The role of digitalization in our lives is reaching new heights. Compared to the past, now more people spend more time doing more things online.

In this context, to meet the increasing demand of users (differentiated by gender and age, etc.) for digital interfaces, the diversified design of interfaces is also continuously developing. Digital interface design includes design elements, such as symbols, colors, and layout. The interface layout determines the position and direction, organizational complexity, cognitive consistency and predictive ability of the information display and affects the user's perception of information intensity, complexity and logic [2]. In modern daily life, there is much stimulating information in digital interface elements [3]. Hence, the organization process of layout elements requires repeated scrutiny and verification. This is a coordinated design and iterative process involving multiple elements. A reasonable layout element combination of interfaces could meet the users' aesthetic needs and allow them to concentrate on the task itself, reducing their cognitive load, shortening the cognitive time and improving interaction efficiency. On the other hand, a disorganized interface layout would cause problems, including a long search time, delayed decision-making, reduced focus on main tasks, and excessive cognitive load [4]. At present, there has been some research on user interface layout design. Störrle [5] indicated that the layout should be considered in line with consumers' use habits. Oakley and Daudert [6] indicated that usability is the main principle for building easy-to-use interfaces. Raeisi *et al.* [7] used chain value analysis for interface layout

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design. Based on the principle of cognitive law, Ji *et al.* [8] used the form of objective function variables on the interface layout. These studies have all begun to be considered from the human point of view, and they reflect the ''user-centered'' design concept in the interface layout. However, it should also be noted that there are still few specific analyses of gender differences in the interface design process from the gender perspective. Therefore, the first goal of this research was to design a useful and usable layout of a visual information interface to explore whether there is a correlation between the interface layout and the gender of users.

Data from Statcounter show that digital interfaces designed for male and female characteristics are increasing year by year. This phenomenon is positively correlated with the number of users of the global digital Internet. For example, as of June 2020, the proportion of men and women using the Internet in China is 51:49, which is basically the same as the total population of men and women (51.1: 48.9) [9]. This phenomenon led us to discover that the demand for gender personalized interface design is increasing. The purpose of personalized design is to improve the interface experience of male and female users. User experience is the focus of human-computer interaction research. The user experience of digital interfaces is primarily embodied in aesthetic experience, value experience and emotional experience. The emotional state of the user can be most intuitively expressed, reflecting the level of user experience. Emotion is an effective way to measure user experience on digital interfaces [10]. Bradley *et al*. [11] found that when people view emotionally stimulating pictures, pupil diameter increases, accompanied by changes in skin electrical conduction, confirming that the reaction to watching emotional pictures is related to an increase in sympathetic nervous system activity. Based on the three-level theory of emotions, Guo *et al*. [12] measured the subjective emotions and physiological indicators of users when browsing the web and found that the three levels of emotional experience have an interactive effect and will, to some extent, affect users' behavior and intentions. Li *et al*. [13] used the PAD emotional scale to record the emotional state of subjects when browsing different music websites, collected the subject's eye movement data with an eye tracker, and established the regression between eye movement indicators and user emotions using the partial least squares method. These studies demonstrate that the main sources of emotional stimulation are pictures and words. However, research on using digital interface layouts as a stimulus source is relatively lacking. At the same time, most emotional experimental technology methods basically focus on eye tracking [14], behavioral response, Event-Related Potential (ERP), Near-Infrared Spectroscopy(NIRS) and other physiological measurement methods and subjective observation methods. For example, Chiang [15] used the perspective of subjective observation to test whether gender differences in emotional expression are stable in interpersonal relationships. Wang *et al.* [16] used behavioral response experiments to present behavioral evidence of gender differences in recognition and memory tasks in emotional conflict situations. These studies demonstrate that emotions have gender differences in individual emotional response changes [17]. However, as far as we know, there are relatively few evaluation experiments that combine interface layout and emotional gender differences. Therefore, this research began with the subjective observation evaluation, behavioral response evaluation and NIRS technical evaluation to comprehensively analyze the reaction state of the emotional conflict between men and women under different interface layouts.

NIRS is a brain function detection tool, and its main principle is the interaction of light with brain tissue. It has good time resolution, noninvasive wearability, and ease of carrying and easy-to-operate modes and is suitable for many scientific research settings [18]. At the same time, NIRS has also been combined with the behavioral response experimental designed by E-prime software to measure changes in the concentration of oxygenated hemoglobin in the prefrontal cortex to confirm the brain's response in the context of emotion [19]. Therefore, compared to other devices, NIRS has portability and anti-interference characteristics, so it is more suitable for monitoring the collection of cerebral cortex signals during interface visual observation.

In this research, based on the basic interface layout framework, we replanned the layout elements to establish different interface layouts according to the principles of visual organization in the laws of human cognition using the NIRS device and E-prime software. Through the reaction time and brain changes in oxygen levels, we determined whether there are emotional conflicts (positive emotions and negative emotions) and gender differences under the cognitive choice of specific layout-related conditions. We used 32 channels to cover the prefrontal cortex (PFC) to obtain signals corresponding to the brain. Combining brain physiological data and subjective scale results, it is helpful for users of different genders to choose appropriate layout styles to develop a personalized digital interface layout user experience.

## II. DEFINITIONS AND ASSUMPTIONS

### A. DEFINITION OF INTERFACE LAYOUT

For the digital interface layout, the task structure and information content that it possesses are certain, i.e., the Cognitive task characteristics are clear. From the perspective of the characteristics of cognitive tasks, this research divides the digital interface layout into three categories according to various aspects that affect the complexity of cognitive tasks: single-level interface layout, two-level interface layout, and multilevel interface layout. As shown in Figure 1, the single-level interface layout has a small number of main tasks and can usually complete all operations with only a one-time boot or no boot (without a typical navigation structure) in the execution process, such as an up-down layout and left-right layout. The double-level interface layout has a relatively large number of main tasks with a more complicated structure. It usually requires a two-time boot to start the mission

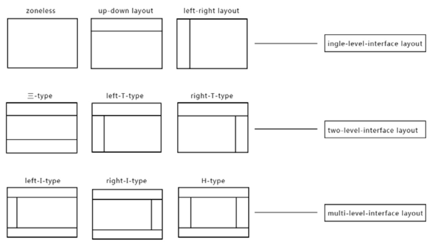


**FIGURE 1.** **Three interface layouts based on cognitive task characteristics. (☰, I and H are intuitive expressions of the layout style and only represent the author's personal and objective feelings.)**

operation, such as the ☰-line and T-type layouts. The multilevel interface layout has numerous main tasks, and the structure is complex. It requires three or more boots and skips (an increase in the proportion of navigation structure) to start operations, for example, the I-type and H-type layouts.

As of June 2020, the number of online shopping users in China reached 749 million, an increase of 39.12 million from March 2020, accounting for 79.7% of total Internet users [20]. Therefore, this study selected the main interface of a shopping website as the experimental object. This main shopping interface contains rich layout elements, clear functional division, complex cognitive tasks, and hierarchical nesting relationships between functional regions. Compared to the low-level interface layouts (single-level and two-level), the layout changes caused by the structure and position of the navigational elements in a multilevel digital interface are more intricate and diverse. Therefore, this research is specific to three fundamental frameworks: H-type (Scheme A), left-I-type (Scheme B) and right-I-type (Scheme C) layouts. Figure 2 shows the numbers that represent the important hierarchical relationship of navigation elements from high to low (1 > 2 > 3 > 4).

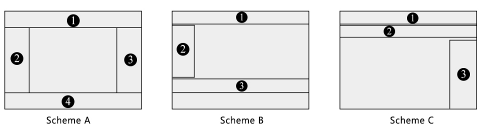


**FIGURE 2.** **Three basic layout frameworks based on the multilevel interface layout conditions: Scheme A (H-type layout), Scheme B (left-I-type layout), and Scheme C (right-I-type layout).**

The research object of digital interface layout design was to consider how to arrange information in a limited space. Taking the shopping interface as a two-dimensional plane with a size of 1920 px × 1080 px, the location of the main display area of the product is determined without changing the basic layout frame. The layout elements are represented by e. By altering the relative position and size of layout elements in the interface, 9 (3 × 3) schemes are designed in total, as shown in Figure 3. The size of the product's main display area of Scheme A is 692 px × 514 px, in which there are 5 layout elements of A-1, and the scaling relation of each size is e1 > e3/e4 > e2 > e5. A-2 has

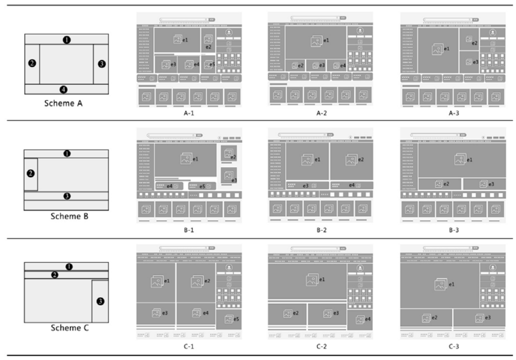


**FIGURE 3.** **Three groups of 9 interface layouts.**

4 layout elements, each size the proportional relationship is e1 > e2/e3/e4. A-3 has three layout elements with the proportional relationship e1 > e2/e3. The size of the main display area of the product in Scheme B is 997 px × 543 px, in which there are 5 layout elements of B-1, and the relationship is e1 > e2/e3 > e4/e5. There are 4 layout elements in B-2, with the proportional relationship e1/e2 > e3/e4. In B-3, there are 3 layout elements with the relationship e1 > e2/e3. The size of the main display area of the Scheme C product is 1193 px × 760 px, in which there are 5 layout elements for C-1, and the relationship is e1/e2 > e3/e4 > e5. There are 4 layout elements for C-2, with proportional relationship e1 > e2/e3 > e4; C-3 has 3 types of layout elements with e1 > e2/e3.

In the main display area of the product, the layout elements are processed in terms of spatial position and scaling relationship. To obtain the organizational relationship of information in layout elements, a questionnaire for evaluating the complexity similarity of interface layout schemes was created using a 5-point Likert scale before the experiment, and 40 people were invited to participate in the survey (male-female ratio 1: 1). The questionnaire shows that the acceptance degree of interface complexity similarity between Schemes A and B was approximately 24.77%, and that between Schemes B and C was approximately 85.23%. Based on the results of this subjective observation, further exploration was performed on the interface layout cognition and emotional conflict evaluation.

### *B. EXPERIMENTAL HYPOTHESIS*

According to the results of the subjective evaluation in the experimental preparation stage, participants' emotional assessment of the complexity similarity of the three schemes A, B, and C was evidently polarized. Therefore, a hypothetical experiment was conducted based on the tristimulus oddball paradigm. Experiment 1 tests emotional conflict for the basic layout. Experiment 1-1 set Scheme B as the target stimulus, Scheme C as the distracting stimulus, and Scheme A as the standard stimulus, while Experiment 1-2 set Schemes A, B and C as the target, distracting and standard stimuli, respectively. Experiment 2 conducted an

**TABLE 1. The setting of specific stimulus items for 9 programs.**

| Layout number | A-1 | A-2 | A-3 | B-1 | B-2 | B-3 | C-1 | C-2 | C-3 |
|---|---|---|---|---|---|---|---|---|---|
| | | Experiment 2-1-1 | | | Experiment 2-1-2 | | | Experiment 2-1-3 | |
| Experiment 2-1 (3 groups) stimulus name | distracting stimulus | target stimulus | standard stimulus | target stimulus | standard stimulus | distracting stimulus | standard stimulus | target stimulus | standard stimulus |
| | | Experiment 2-2-1 | | | Experiment 2-2-1 | | | Experiment 2-2-1 | |
| Experiment 2-2 (3 groups) stimulus name | target stimulus | distracting stimulus | standard stimulus | distracting stimulus | target stimulus | standard stimulus | target stimulus | distracting stimulus | standard stimulus |

emotional conflict test for the interface element layout of specific products' main display area and set the stimulus according to a preliminary investigation, as shown in Table 1. The E-prime experiment was designed so that the behavioral outcome directly reflects the participant's choice of interface layout. Through preliminary experimental preparations, the variations in HbO (oxygenated hemoglobin in the brain) concentration reflect the influence of participants on various stimuli and emotional conflicts. We made predictions for the experiment. In Experiment 1-1, the average content of the relative change in HbO concentration of Scheme B was higher than that of Scheme A. In Experiment 1-2, the average content of relative change of HbO concentration of Scheme A was higher than that of Scheme C. Experiment 2 performed emotional conflict response to 9 schemes. The relative change in HbO concentration exhibited an apparent contrast and sex differences. The particular situation described by emotions and the HbO concentration variation problem require further analysis of the experimental data

## III. METHOD

### A. PARTICIPANTS

The experiment recruited 20 participants (10 males and 10 females) aged between 22 and 28 (M = 24.465, SD = 1.67). All participants had normal or corrected eyesight without color blindness or color weakness. All participants voluntarily agreed to participate in this experiment. The experiment complies with the ethics codes of the American Psychological Association and the World Medical Association. Before the experiment, all participants received training and were familiar with the operation process.

### B. EXPERIMENTAL METHOD

Most studies of emotional conflict adopt the lexical paradigm [21] to observe emotional images and collect emotional samples. Since the experimental material in this study was not emotional images, the oddball paradigm was applied. The classic oddball paradigm randomly presents two stimuli of the same sensory channel in an experiment. There are numerous stimulus sources in this study. Therefore, the oddball is modified by extension to three stimuli (target stimulus, analytical stimulus and standard stimulus) when conducting the experiment. To avoid the different HbO concentrations caused by changes in the probability of the target stimulus, the proportions of the target, distracted and standard stimuli to the total number of stimuli were kept constant at 10%, 10% and 80%, respectively, between the two experimental modules. To minimize interference caused by related factors, such as colors and icons, all images were decolorized in Photoshop and placed in the central area of the screen with a black background color (R: 35, G: 24, B: 21) to highlight the main body of the stimulation interface. All stimuli appeared on a 15.6-inch display screen. Subjects sat at a distance of 55-60 cm from the display screen and looked at the computer screen horizontally. E-Prime 2.0 software was used for the experimental design and behavioral data collection tasks.

### C. EXPERIMENTAL PROCEDURES

For the sake of being familiar with the experimental procedure, each participant was required to complete the practice test before completing the formal experiment.

Following the experimental instructions, participants finished the stimulus image of the practice stage and pressed the corresponding keyboard button to obtain feedback. A total of 5 cycles were performed without behavioral data collection. The formal experiment consisted of two groups. Experiment 1 required participants to react emotionally to the two basic interface layout frameworks, while Experiment 2 asked them to react emotionally to the 9 schemes of layout elements divided into two groups.

#### 1) EXPERIMENT 1

Experiment 1 was divided into two groups of experiments. In Experiment 1-1, participants pressed the button to basic interface layout frameworks that produce positive emotions, while participants pressed the button to the framework that produced negative emotions in Experiment 1-2. The center of the screen was fixed to "+". The standard stimulus, distraction stimulus and target stimulus appear in pseudorandom order. The number of cognitive elements in the experiment is large and complex. For participants to better understand the meaning of the interface, the stimulus exposure time was set to 2000 ms, and the stimulus interval was 500 ms to eliminate visual residue. In Experiment 1, the standard stimulus occurred 48 times (the number of standard stimuli accounted for 80% of the total number of stimulus sequences), the target stimulus appeared 6 times (the number of target stimuli accounted for 10% of the total number of stimulus sequences), and the distracted stimulus appeared 6 times (the number of target stimuli accounted for 10% of

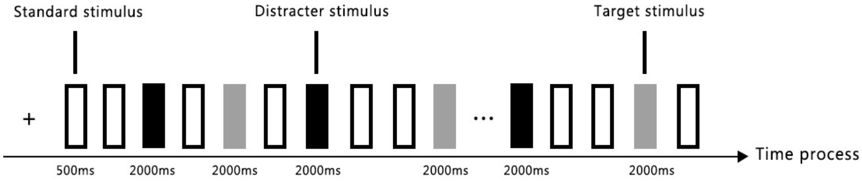


**FIGURE 4.** Experimental process and experimental structure of experiment 1 and experiment 2.

the total number of stimulation sequences). Participants were told to respond by pressing the "space" key (on the computer keyboard) as soon as possible. After Experiment 1 was completed, they rested for 15 s before entering Experiment 2. The process of Experiment 1 is shown in Figure 4, and the duration was approximately 10 minutes.

#### 2) EXPERIMENT 2

Experiment 2 was specifically divided into two groups of experiments, which are further divided into three groups. Hence, there were 6 groups in total. Experiment 2-1 was where the participants responded to the interface layout elements that they think produces positive emotions. Experiment 2-2 was where participants thought they produced negative emotions. Participants were told to respond by pressing the "space" key (on the computer keyboard) as soon as possible. The stimulus exposure time and number of exposures were the same as in Experiment 1. The experimental procedure of Experiment 2 lasted approximately 20 minutes.

### *D. STATISTICAL ANALYSIS*

In the two experiments, the participation efficiency of each participant exceeded 90%. To research the influence of gender differences on the interface layout, we primarily analyzed RT (Reaction Time) data. The RT data were directly obtained from E-prime software; after deleting the data that did not give a response, a mixed analysis of variance was performed under a general linear model, together with a paired sample $t$-test to examine gender differences in positive and negative emotions during the process of choosing interface layout.

### *E. NIRS DATA ACQUISITION*

This experiment applied the NirSmart portable brain-function imaging system for HbO signal acquisition. Compared to HbR, HbO concentration changes are more sensitive to task stimulation and have a higher signal-to-noise ratio [22]. Therefore, this study only focused on HbO concentration for specific analysis. The sampling frequency was 10 Hz, and the wavelengths were 760 nm and 850 nm. The PFC is one of the important parts of the emotional central pathway [23], and it plays an important role in emotional processing. Therefore, this experiment employed a $3 \times 7$ multichannel layout and set 21 SD probes, including 11 light sources and 10 detectors, in the PFC in accordance with the international 10/20 system

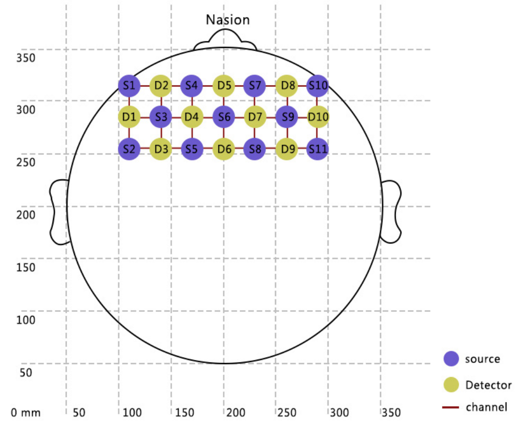


**FIGURE 5.** PFC full area measurement channel configuration.

placement order. The two types of optrodes were distributed in intervals of 300 mm, forming 32 NIRS channels (Figure 5).

### *F. NIRS DATA ANALYSIS*

Our research completed continuous NIRS recording, and the data were processed offline and segmented in line with the event-display marker set. The marker selects the time from 200 ms before the appearance of the target stimulus to 1000 ms afterwards as a time interval. NirSpark software was used to preprocess the NIRS data by removing the interference time period and artifact signals. The processing rule was that if a certain time period is selected, the data during this period will be directly removed. The remaining two segments of data will remain unchanged for the previous segment of data, while the latter segment of data will be stitched in the vertical direction with OD (optical density) as the dimension, converting light intensity to optical density, selecting the Butterworth bandpass filters for filtering noise and interference signals, converting optical density to blood oxygen concentration, and setting "0s-120s" as a block paradigm time for hemodynamic response function (HRF), and "-2s-0s" as the reserved baseline state. All differential path-length factors (DPF) were set to 6.0. According to previous research, Liu *et al.* [24] used the Butterworth bandpass filter to filter the physiological noise of endothelial activation below 0.021 Hz and to remove the frequency band above 0.145 Hz, which primarily reflects respiration and cardiac activities to avoid Mayer wave interference. The order of the

**TABLE 2.** Descriptive statistics of women and men choosing different numbers of layout elements.

| Project name | Number of cases | average value | maximum value | minimum value | standard deviation | T test | significance |
|---|---|---|---|---|---|---|---|
| 3 layout elements for women | 10 | -0.1 | 1 | -1 | 0.73786 | -0.429 | 0.678 |
| 4 layout elements for women | 10 | 1.2 | 2 | 0 | 0.78881 | 4.811 | 0.001 |
| 5 layout elements for women | 10 | -1 | 1 | -2 | 1.05409 | -3.881 | 0.004 |
| 3 layout elements for men | 10 | 0 | 1 | -1 | 0.8165 | 0 | 1 |
| 4 layout elements for men | 10 | 1.4 | 2 | 0 | 0.69921 | 6.332 | 0 |
| 5 layout elements for men | 10 | -0.8 | 1 | -2 | 1.13529 | -2.228 | 0.043 |

low-pass filter was 3, and the order of the high-pass filter was 5. The filtering operation used the time domain reversal method to compensate for the phase, and the filtered result did not have any time domain offset influence. According to the modified Beer-Lambert law, formula (1) and (2), the signal was converted to HbO and HbR relative concentrations in the format as follows:

$$OD^{\lambda_i} = \ln \frac{I_{oi}}{I_I} = \left(\varepsilon_{HbO}^{\lambda_i}\right) \times r \times DPF^{\lambda_i} i = 1, 2, 3 \quad (1)$$

$$\Delta OD^{\lambda_i} = \left(\varepsilon_{HbO}^{\lambda_i} \Delta C_{HbO}\right) \times r \times DPF^{\lambda_i} i = 1, 2, 3 \quad (2)$$

The variable $\varepsilon$ is the wavelength-dependent extinction coefficient. The DPF is the effective length of the source and the detector, and r is the linear distance from the probe. The delta optical density ($\Delta$OD) refers to the change in light absorption. $\Delta$CHbO represents the relative concentration changes in HbO, and the following equation (3) was used to calculate HbO2 [25]:

$$\Delta C_{HbO} = \begin{pmatrix} \varepsilon_{HbO}^{\lambda_1} \\ \varepsilon_{HbO}^{\lambda_2} \\ \varepsilon_{HbO}^{\lambda_3} \end{pmatrix}^{-1} \begin{pmatrix} \Delta OD^{\lambda_1} / \left(r \times DPF^{\lambda_1}\right) \\ \Delta OD^{\lambda_2} / \left(r \times DPF^{\lambda_2}\right) \\ \Delta OD^{\lambda_3} / \left(r \times DPF^{\lambda_3}\right) \end{pmatrix} \quad (3)$$

The block average was generated by superimposing and averaging the blood oxygen concentration collected from each of the four paradigms. For each preprocessed experimental data based on the GLM (Generalized Linear Model), the reference wave of the HbO change of each channel was set, and the $\beta$ value of the interface layout selection behavior response on each channel was subjected to a paired sample t-test.

## IV. EXPERIMENTAL RESULTS

### A. RESULTS OF THE MAIN OBSERVATION

This study investigated and evaluated whether the arrangement of layout elements between different interface layout forms of the online shopping interface caused emotional conflict. We designed a 5-point Likert scale, and the emotional degrees from negative to positive were -2, -1, 0, 1, and 2. Descriptive statistics were applied to the evaluation results (Table 2). A total of 76.23% of women and 52.47% of men believe that the scheme organized by 5 layout elements has high complexity and easily produced negative emotions, such as irritability and anxiety ($p < 0.05$). A total of 86.24% of women and 78.46% of men thought that the scheme organized by 4 layout elements produced more positive emotions and tended to use it in actual shopping ($p < 0.05$). A total of 64.12% of women and 55.83% of men had little mood swings for the scheme of three layout elements ($p > 0.05$).

Based on the subjective evaluation results, further exploration was performed on the emotional conflict response and gender differences caused by the emotional conflict changes of the stimulus response to the main display area interface layout of the product.

### B. BEHAVIORAL DATA RESULTS

#### 1) EXPERIMENT 1 RT DATA RESULTS

To standardize the data results, RT was set in the range of 200 ms $\pm$ 30 ms. Values smaller than the range indicate that the participant paid less attention, and values greater than the range indicate that the participant was distracted by other factors in the environment. Experiment 1-1 tested the positive emotional response to three basic layouts. In Experiment 1-1, the average RT of Scheme A for women was 215.82 ms ($t = 53.228$, $p < 0.05$); the average RT of Scheme B was 250.25 ms ($t = 19.5$, $p < 0.05$); and the average RT of Scheme C was 276.42 ms ($t = 10.476$, $p < 0.05$). For men in Experiment 1-1, the average RT of Scheme A was 267.88 ms ($t = 11.797$, through the participant's response button); the average RT of Scheme B was 220.94 ms ($t = 21.974$, $p < 0.05$); and the average RT of Scheme C was 322.42 ms ($t = 15.415$, $p < 0.05$). In the box diagram (Figure 6), it can be seen intuitively that men and women exhibited different options in all basic layout schemes.

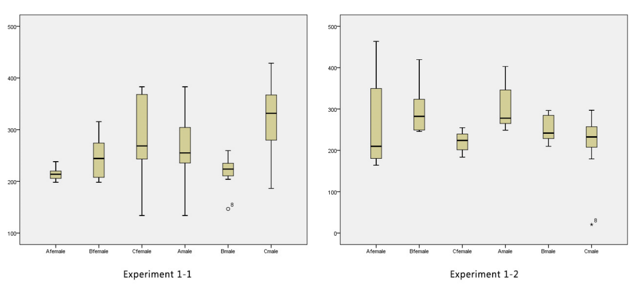


**FIGURE 6.** Experiment 1 (Experiment 1-1: positive emotion button response; Experiment 1-2: negative emotion button response). Box diagram of male and female RT data.

Women and men had positive emotions and pressed the button to Scheme A and Scheme B, respectively. Experiment 2-1 tested the response to negative emotions of three basic layouts. In Experiment 2-1, the average RT of Scheme A for women was 263.94 ms ($t = 7.213$, $p < 0.05$); the average RT of Scheme B was 296.232 ms ($t = 17.14$, $p < 0.05$); and the average RT of Scheme C was 221.06 ms ($t = 30.662$, $p < 0.05$). In Experiment 2-1, the average RT of Scheme A was 300.31 ms ($t = 18.042$, $p < 0.05$); the average RT of Scheme B was 249.84 ms ($t = 25.116$, $p < 0.05$); and the average RT of Scheme C was 215.26 ms ($t = 8.963$, $p < 0.05$). In the box diagram (Figure 6), it can be seen intuitively that both men and women exhibited negative emotional responses to Scheme C.

### 2) EXPERIMENT 2 RT DATA RESULTS

Through the comparison of box diagrams, it can be seen that during the process of button response of positive emotion in Experiment 2-1, the average RT of women in Scheme A-2 was 209.37 ms ($t = 27.005$, $p < 0.05$), the average RT of Scheme B-3 was 219.36 ms ($t = 31.068$, $p < 0.05$), and the average RT of Scheme C-2 was 216.26 ms ($t = 25.094$, $p < 0.05$). Nevertheless, the average RT of men in Scheme A-2 was 217.76 ms ($t = 37.821$, $p < 0.05$), the average RT of Scheme B-3 was 209.54 ms ($t = 35.752$, $p < 0.05$), and the average RT of Scheme C-3 was 214.63 ms ($t = 23.296$, $p < 0.05$) (Figure 7).

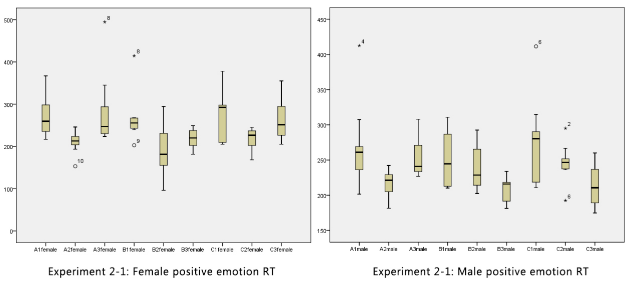


**FIGURE 7. Experiment 2-1 (positive emotional response). Box plot of RT data for males and females.**

During the button response of negative emotion in Experiment 2-2, the average RT of women in Scheme A-1 was 214.1 ms ($t = 26.686$, $p < 0.05$), the average RT of Scheme B-2 was 217.79 ms ($t = 30.122$, $p < 0.05$), and the average RT of Scheme C-1 was 210.33 ms ($t = 24.971$, $p < 0.05$). However, the average RT of men in Scheme A-1 was 222.39 ms ($t = 56.67$, $p < 0.05$), the average RT of Scheme B-1 was 228.93 ms ($t = 24.771$, $p < 0.05$), and the average RT of scheme C-1 was 224.98 ms ($t = 24.369$, $p < 0.05$) (Figure 8).

### 3) RESULTS OF GENDER DIFFERENCES

In cognitive tasks of the basic interface layout framework, men and women exhibited a statistically significant main effect relationship. Under the condition of a positive emotional response, women chose Scheme A, while men

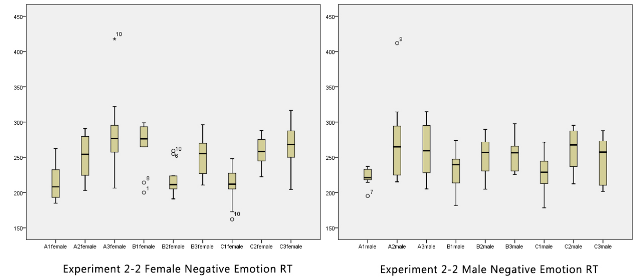


**FIGURE 8. Experiment 2-2 (negative emotional response). Box plot of RT data for males and females.**

chose Scheme B, highlighting a gender difference. In the cognitive task selection of nine layout schemes designed by a combination of different numbers of layout elements, there was no gender difference in the cognitive emotion conflict of the interface layout with five-element combinations, but there were gender differences in the layout consisting of four and three elements. Therefore, through the analysis of RT in behavioral experiments, we concluded that there are emotional conflicts and gender differences in interface layout tasks. The particular gender difference in the interface layout with different numbers of layout elements should be further analyzed based on the results of NIRS data.

## C. NIRS EXPERIMENTAL RESULTS

Combined with behavioral data, Scheme A-2 and Scheme B-3 are good interface layouts for eliciting positive emotions in men and women. Therefore, this study only conducted NIRS analysis for Scheme A-2 and Scheme B-3 to explore the optimal choice between men's and women's specific interface layout schemes. The preliminary experimental analysis revealed that GLM set the ideal HRF for each example experiment to calculate the matching degree between the experimental HRF value and the ideal HRF value [26]. The collection of beta values for each channel represents cortical activation. Table 3 shows the beta values of 32 channels for men and women in Scheme A-2 and Scheme B-3, among which S6D5 and S6D6 are shared channels between the left and right frontal lobes. In the correlation statistical analysis, the data length of each block example was set to the first 80 s, and the block average and standard deviation were calculated to ensure the reliability of the correlation analysis. The specific description is as follows. In Scheme A-2, for females, the highest beta value of LPFC (left prefrontal cortex) was 0.5934, and the lowest was -0.6019. The highest beta value of RPFC (right prefrontal cortex) was 0.2341, and the lowest was -0.0701. For males, the highest beta value of LPFC was 0.4095, the lowest was -0.4372, the highest beta value of RPFC was 0.2853, and the lowest was -0.0492. In Scheme B-3, for females, the highest beta value of LPFC was 0.4195, and the lowest was -0.3734; the highest beta value of RPFC was 0.3176 and the lowest was -0.0842. For males, the highest beta value of LPFC was 0.6821, the lowest was -0.2438, the highest beta value of RPFC was 0.3012, and the lowest was -0.0379.

**TABLE 3.** Descriptive statistics of male and female PFCs in scheme A-2 and scheme B-3.

| Scheme | LPFC | | | RPFC | | |
|---|---|---|---|---|---|---|
| | number of channels | average value | standard deviation | number of channels | average value | standard deviation |
| A-2 female | 17 | 0.0034 | 0.0812 | 17 | -0.0063 | 0.0975 |
| A-2 male | 17 | 0.0026 | 0.0721 | 17 | -0.0042 | 0.0877 |
| B-3 female | 17 | 0.0021 | 0.0704 | 17 | -0.0057 | 0.0793 |
| B-3 male | 17 | 0.0032 | 0.0793 | 17 | -0.0061 | 0.0945 |

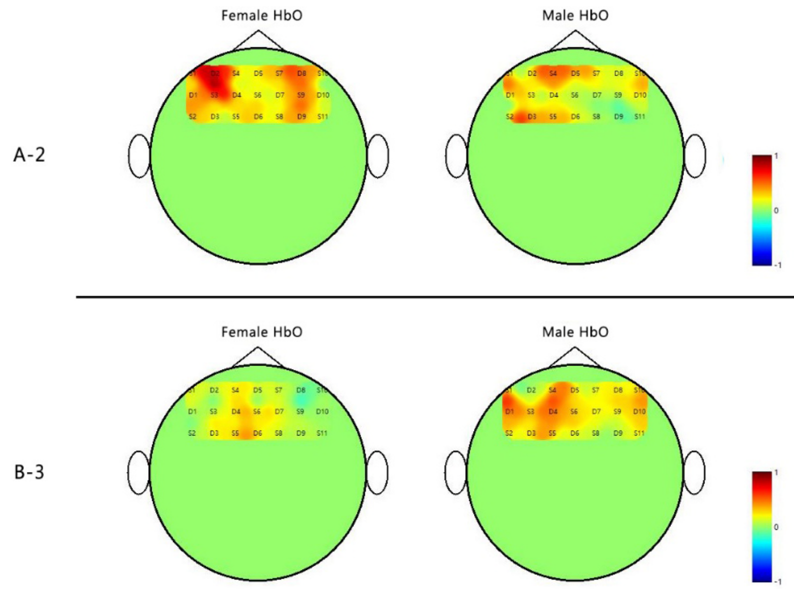


**FIGURE 9.** HbO head mold imaging of experiment 1 and experiment 2.

Figure 9 shows the HbO head model imaging in different colors. The higher the $\beta$ value is, the redder the image; in contrast, the lower the $\beta$ value is, the bluer the image.

### 1) RESULTS OF SCHEME A-2

LPFC reflects positive emotions. The $\beta$ value of LPFC in Scheme A-2 in Figure 9 was higher ($p < 0.05$), and the $\beta$ value of RPFC was not significant compared to LPFC ($p > 0.05$). Among the 17 channels of the LPFC, specifically, the S1D2, S3D2, S4D2, S2D3, S3D3, and S5D3 channels showed evident activation ($p < 0.05$). The blood oxygen concentration activation of men and women was relatively frequent, and activation was obvious between 60 s-90 s when entering the experiment and between 180 s-150 s at the end of the experiment. Combined with the behavioral data, the cognitive process of Scheme A-2 shows obvious mood swings.

A paired-sample $t$-test was performed on HbO concentration changes in the emotional conflict response in 6 channels. The results show that women had high $\beta$ values on S1D2 ($t = 5.35$, $p < 0.05$), S3D2 ($t = 4.28$, $p < 0.05$), and S4D2 ($t = 4.36$, $p < 0.05$), while in S2D3, the $\beta$ values of S3D3 and S5D3 were lower than those of other channels ($p > 0.05$), but the margin is clear. Men had a significant decrease in the $\beta$ value compared to women in S1D2 ($t = 3.81$, $p < 0.05$), S3D2 ($t = 4.06$, $p < 0.05$) and S4D2 ($t = 5.24$, $p < 0.05$), but in S2D3 ($t = 5.43$, $p < 0.05$), S3D3 ($t = 3.48$, $p < 0.05$), and S5D3 ($t = 4.08$, $p < 0.05$) channels, the $\beta$ value varied to a large extent ($p > 0.05$). This finding shows that men and women have emotional conflicts in the cognitive process of Scheme A-2, and women gave a more significant response than men.

### 2) RESULTS OF SCHEME B-3

In Figure 9, the $\beta$ value of LPFC in Scheme B-3 was higher ($p < 0.05$), and the $\beta$ value of RPFC was not significant compared to LPFC ($p > 0.05$). In the 17 channels of the LPFC, S1D1, S2D1, S3D1, S3D4, S4D4, S5D4, and S6D4 were largely activated ($p < 0.05$). The activation of blood sample concentration for men was relatively frequent, while the blood oxygen concentration of women was relatively flat, except for the S5D4 channel. This shows that in the cognitive process of B-3, males had greater mood swings relative to females.

A paired-sample t-test was performed on the changes in HbO concentration in emotional conflict response in 7 channels. The beta value of males in channel 7 was significantly higher ($p < 0.05$). For women, the $\beta$ values were higher and relatively balanced at S4D4 ($t = 2.49$, $p < 0.05$), S5D4 ($t = 3.04$, $p < 0.05$), and S6D4 ($t = 4.27$, $p < 0.05$). In S1D1, S2D1, S3D1, and S3D4, stimulus inhibition occurs, and the change in the $\beta$ value was smaller than that in the other channels. This indicates that there are emotional conflicts between men and women in the cognitive process of Scheme B-3, and men provided a more significant response than women.

## V. DISCUSSION

In a digital interface, it is not simply a linear relationship between interface layout elements. The layout form will change according to the amount of information and changes in information deconstruction, and the two are closely related. We first divided the interface layout into three basic framework forms and with the basic framework unchanged, analyzed the organizational relationship between the layout elements and established 9 interface layouts. Through behavioral experiments and NIRS experiments, we explored gender differences in the cognitive tasks of interface layouts.

In behavioral experiments, we observed that there were obvious gender differences in the cognitive choices of the basic frame layout under the influence of positive emotions, which is related to the different visual processing strategies of men and women [27]. In the cognitive task response through pressing buttons for nine interface layouts, those that evoked negative emotions did not show obvious gender differences, while layouts that gave rise to positive emotions did.

The hemodynamic response reflects the blood oxygenation level in the brain. Partial changes in HbO signals are common parameters of NIRS and are closely related to changes in brain nerve activity [28] that indirectly measure changes in brain nerve activity by detecting hemodynamic changes in the cerebral cortex [29]. It is generally accepted that hemodynamic and electroneurographic signals (e.g., EEG) provide supplementary information about the underlying neural mechanisms in various cognitive functions [30]. Using fMRI (functional magnetic resonance imaging) or fNIRS (functional near-infrared spectroscopy) technology, many studies have demonstrated identifiable hemodynamic response data between positive and negative emotions [31]. PFC has less motion, and the signal is strong and stable. Therefore, research on emotional conflict has primarily focused on the PFC [32]. Research has found that for positive emotional expectations, the activation of the PFC on the left dorsolateral side is higher than that of negative emotions [33]. Therefore, in this study, the PFC channel was fully covered, and the LPFC and RPFC channels were specifically divided. The brain induces cortical activation through visual sensory stimulation. We found that there was a correlation between overall emotional valence and HbO activation in the bilateral PFC and that RT was positively correlated with brain HbO. In the analysis of Scheme A-2 and Scheme B-3 under the influence of positive emotions, both men and women exhibited significant HbO responses in the 17 RPFC channels, and gender did differences exist.

If note, this study did not take into account symbols, colors or other elements involved in the interface layout, and it is necessary to conduct overall research on the interface layout in the future. The combination of actual design practice and NIRS experiments is important to further research on interface design in the neural field.

## VI. CONCLUSION

This research implemented a shopping interface layout as the research object. Through the analysis of behavioral data and NIRS data, it is proposed that there is a specific correlation between digital interface layout and user gender. Under the influence of positive emotions in the primary interface, women preferred the four-layout-element combined interface based on the H-type interface layout frame, and men preferred the interface combined by three layout elements based on the left-I-type layout frame. In the primary interface, both men and women had negative emotions on the combination of five layout elements based on the right-I-type layout frame. The interface layout design should be personalized according to the emotional characteristics of men and women. Therefore, these findings will aid the research and development of gender-specific designs of digital interfaces.

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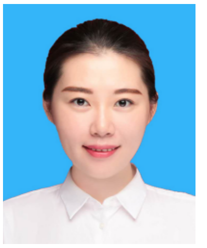

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