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Original Research Article

Research on Key Methods of Visual Human-computer Interaction Comfort Quantifacation in Multidimensional Information Space

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ABSTRACT

With the increase of information exchange types and the acceleration of information exchange speed, people not only pursue fast and efficient interaction effect, but also begin to pursue natural and harmonious human-computer interaction comfort experience physically and psychologically. Therefore, human perceived comfort has become an important index in the design of modern human-computer interaction system. However, since comfort is the subjective feeling of human body, it is difficult to realize quantitative measurement and evaluation in the design process, which brings great difficulties to computer intelligent human-computer interaction design and scientific evaluation. Vision is the most important sense of human beings. More than 80% of all kinds of information received by people from the outside world is obtained through vision. Vision is an important means of human-computer interaction in complex multi-dimensional information space, and it is also the most intuitive source and effect embodiment of human comfort perception. Through a large number of experiments, import the test data into the software Origin, and draw the change curve of visual comfort with reading time, which fit with the S-shaped curve as the reference. In this way, the relationship between visual comfort and reading time can be obtained. The mathematical model of the relationship between reading time and visual comfort is established, and experiments are carried out to verify the corresponding mathematical model relationship.

Keywords: *Vision; Human Computer Interaction; Quantification of Comfort; Multi-information Fusion; Matching Model*

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1. Introduction

With the development of economy and society, natural and harmonious interaction has become the ultimate goal of modern and future human-computer interaction design, and it needs the coordinated participation of human vision, hearing, tactile sensation and other multi-senses. With the rapid development of modern human-computer interaction technology and information system, it requires human-computer interaction system to be more accurate, fast, efficient and comfortable. In order to achieve this goal, in the process of human-computer information interaction, we must give full play to the comprehensive efficiency of human vision, hearing, tactile sensation and other perception methods, and form an all-round multi-information fusion interaction system, so that the operator can fully perceive and master information. At the same time, we should balance the perception ability of various sensory organs, and maximize the perception ability of each sensory organ, so as to improve the comprehensive efficiency of human-computer interaction.

2. Visual human-computer interaction

2.1 Research background and significance

Vision is the most important sense of human beings, and comfort is the subjective feeling of human body. The wide application of computer and network technology in particular makes the accurate measurement and scientific expression of color very important and urgent[1]. At present, the research on comfort is generally qualitative description, and quantitative calculation is very difficult. It is unable to establish the quantitative measurement model between visual human-computer interaction and comfort, complete the demand of real-time quantitative measurement in the process of human-computer interaction, provide scientific and quantitative design reference and evaluation standards, and meet the requirements of intelligent design of computer human-computer interaction in the future. Therefore, we should study the perceptual characteristics of visual human-computer interaction in multi-dimensional information space and the integration mechanism of visual, force tactile, auditory and other perceptual systems, detect the visual comfort quantitatively, and build a multi-dimensional information space human-computer interaction comfort measurement calculation model integrating vision, hearing and tactile sense. These experiments can not only measure the comfort of each perceptual system, but also measure the comprehensive comfort of multiple senses at the same time, which can realize the organic integration of visual, auditory, tactile and other multi-information, and use different methods for different requirements, so as to obtain the results most in line with ergonomics. Improving the efficiency and quality of complex human-computer interaction system and providing consumers with more natural human-computer interaction experience has great theoretical significance and application value.

Mobile reading is a popular way of fragmented time management. People can obtain multi-directional and diversified information by reading news and novels on mobile phones. According to the *2019 China Digital Reading White Paper* (**Figure 1**), by 2019, the total number of Chinese digital reading users had reached 470 million. The data of the 18th National Reading survey released by China Academy of Press and Publication also shows that in 2020, the access rate of digital reading methods (online reading, mobile reading, e-reader reading, pad reading, etc.) was 79.4%, an increase of 0.1 percentage points compared with 79.3% in 2019. It can be seen that people spend a lot of time on mobile reading every day. It can be said that mobile reading has become a part of people's life. However, people often suffer from eyestrain such as dry eyes, sore eyes, dizziness and headache after reading on mobile phones for a long time. The word "ashenopia" is derived from the Greek language, which originally means eye weakness. After using the eyes for a long time, it produces adverse reactions such as orbital pain, blurred vision, eye burning, dry eyes, tears and so on.

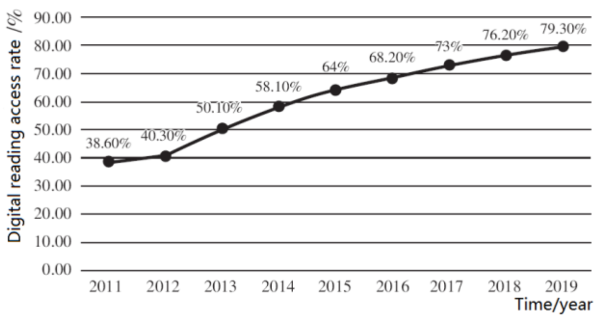

Figure 1. 2019 digital reading white paper.

With the rapid development and popularization of computer technology, mobile phones and tablet computers can also be included in the scope of Visual Display Terminal of personal computer and computing system. VDT syndrome refers to the comprehensive symptoms such as eye discomfort caused by staring at the video terminal for a long time[2]. Visual comfort degree refers to the subjective feeling of the eye when the eye receives external electromagnetic waves such as VDT, which is specifically reflected in the degree of eye fatigue, blinking frequency, visual acuity etc. after using the eye for a period of time. Most of human perception activities are completed through the visual system. At present, the simulation of visual perception is mainly based on the model, in which the sensing information is used to reconstruct the model of the perceived world[3]. This study uses the methods of theoretical analysis and experimental verification to study the multi-dimensional information perceived comfort based on vision. Taking reading mobile e-books as an example, this study studies the subjects' visual comfort after reading mobile e-books for a period of time. It tracks the relationship between their visual comfort and time under certain conditions, and realizes the quantitative calculation of perceived comfort of visual information. Thus the quantitative model of multi-dimensional information human-computer interaction comfort based on vision is established. Finally, the verification test is carried out to verify the model. The research results can be widely used in complex operating systems, virtual reality and other system environments, and they have important theoretical and application value for improving the level of human-computer interaction design.

2.2 Analysis of research status at home and abroad

At present, the main direction of domestic relevant research is on various factors of electronic display equipment and human visual comfort, such as environmental illumination, font, font size, spacing, and color matching, which is more in line with the visual application scene of people in the development of the times. Most of the research is aimed at some main factors in a specific environment of application. The related achievements include the following. Jiang Ying *et al.* studied and summarized the quantitative model of the visual comfort of the information display interface of the visual display terminal (VDT) through the combination of subjective and objective experiments. The study took the dial interface with different color combinations as the test object, took the physiological characteristics such as EEG signals of the subjects as the objective basis, and supplemented by the subjective score of the subjects on the comfort of the dial interface. The evaluation method is scientific. Hou Guanhua *et al.* studied the influence of font size and spacing on the digital reading experience with different age groups. They comprehensively considered the characteristics of reading experience of groups of different ages, adopted the combination of subjective and objective observation and evaluation, selected the font size and spacing as the research variables, and studied the difference of the impact of different font size and spacing on the reading experience of users of different ages based on the standard of visual comfort. In addition, Liu Chang and others quantitatively studied the influence of chromaticity on the visual comfort of stereo images. Cai Jianqi *et al.* studied the influence of environmental illumination of ipad and other electronic products on human visual comfort in the bedtime use environment. It can be seen that there are few overall quantitative studies on visual comfort at present.

3. Evaluation Index

Visual health and comfort is an objective quantitative index of visual fatigue. It realizes the objective evaluation of everyone's eye health and comfort based on the changes of human eye axis and corneal refraction[4]. The main factors affecting visual comfort include illumination level[5], brightness contrast of screen display[6], light environment (such as playground, reception hall, bedroom, etc.), text size, text interval, eye use time, illumination, color combination, age, etc. When establishing the mathematical model of visual comfort, it must be taken into account that visual comfort has two characteristics—"psychological feeling" and "depends on a variety of uncertain factors". We take the change of reading comfort with reading time as an example to carry out the research. According to the literature analysis, we take the usability and perceived visual comfort as the subjective measurement indicators, directly ask the subjects' feelings during the test, and use the scale to measure the subjects' subjective feelings. This method is the most direct method to evaluate whether the vision is comfortable or not. The research scale is shown in **Table 1**.

Table 1. Limited range of visual comfort and human representation state

Visual comfort value	State
0	No fatigue
1	Basically no fatigue
2	Slight fatigue
3	There is obvious fatigue, but it is within the tolerance range
4	Increased fatigue and various eye discomfort

4. Test Part

The design scheme of repeated measurement test between groups is adopted in the test, and the mobile phones with their own reading app is selected as the test standard. The subjects are 20 volunteers aged 19–22. All of them are college students from Northwestern Polytechnical University, and they don't have severe myopia and astigmatism (myopia within 300 degrees and astigmatism within -100 degrees).

In the study of comfort, fatigue is the most important factor in the psychological factors affecting comfort[7]. It is carried out indoor with normal lighting, quiet and comfortable environment. In order to avoid the interference of visual fatigue, all subjects have enough sleep before the test, and are arranged to close their eyes and rest until there is no fatigue before the test, so as to ensure that the subjects can be in a good psychological and physiological state during the test.

Before the test, we record the basic information of the subjects, and explain the test process to the non subjects. Then we uniformly arrange the subjects to rest until the comfort test is 0 (completely comfortable). Every time the subjects use the mobile phone to read e-books for 5 minutes, we immediately ask the subjects about their subjective visual comfort and fill in the scale. Each participant needs 50–60min to complete all contents. The test process is shown in **Figure 2**.

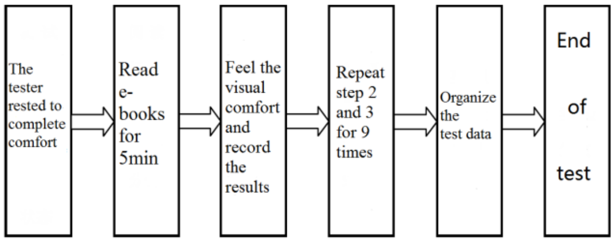

Figure 2. Visual comfort test process.

5. Establishment of Quantitative Mathematical Model of Visual Comfort

Since the study only analyzes the impact of reading time on visual comfort, in order to obtain the mathematical model of visual comfort information perception and the general law between visual comfort and time, it is necessary to ensure that other factors remain unchanged and only record the data of visual comfort at different times. Therefore, the control variable method is adopted in the experiment. 20 subjects were tested for many times in the same time period and the same place, with a total of 20 groups of data. See **Table 2** for the relevant data.

Table 2. Measurement data

Person-time	Time/min									
	0	5	10	15	2025	3035	40	45	50	55
1	0.01	0.01	0.02	0.05	0.140.34	0.781.48	2.19	2.66	2.90	2.99
2	0.01	0.10	0.15	0.25	0.330.64	0.841.50	2.00	2.80	2.90	3.00
3	0.01	0.05	0.05	0.10	0.200.50	0.901.35	1.90	2.50	2.70	2.90
4	0.01	0.02	0.04	0.06	0.120.36	0.721.44	2.20	1.90	1.80	2.00
5	0.01	0.10	0.15	0.18	0.350.70	1.351.80	2.20	2.70	2.85	2.95
6	0.01	0.05	0.10	0.10	0.150.40	0.751.45	2.10	2.55	2.75	2.80
7	0.01	0.02	0.08	0.12	0.160.30	0.701.40	2.15	2.75	2.85	2.95
8	0.01	0.07	0.16	0.21	0.380.62	0.981.38	2.04	2.41	2.68	2.87
9	0.01	0.01	0.06	0.12	0.210.33	0.891.41	1.88	2.34	2.79	2.96
10	0.01	0.02	0.09	0.15	0.310.73	1.051.48	1.95	2.42	2.73	2.84
11	0.01	0.09	0.16	0.31	0.450.68	1.011.42	1.89	2.43	2.82	3.01
12	0.01	0.03	0.05	0.09	0.210.44	0.831.34	1.98	2.56	2.87	2.96
13	0.01	0.08	0.14	0.23	0.310.69	0.981.44	2.08	2.77	2.93	3.05
14	0.01	0.02	0.05	0.17	0.290.49	0.891.35	2.11	2.57	2.72	2.90

Table 2. continued.

15	0.01	0.02	0.04	0.09	0.190.36	0.821.31	2.20	1.97	2.10	2.30
16	0.01	0.07	0.15	0.26	0.350.81	1.251.70	2.12	2.52	2.85	3.15
17	0.01	0.01	0.10	0.13	0.210.40	0.851.52	1.89	2.33	2.55	2.73
18	0.01	0.02	0.04	0.10	0.150.30	0.631.20	2.05	2.75	2.82	3.14
19	0.01	0.01	0.01	0.07	0.170.42	0.961.32	1.93	2.52	2.86	2.97
20	0.01	0.01	0.03	0.08	0.260.45	0.891.56	2.20	2.70	2.86	3.06

For the measured data, take the number of test records as the x-axis and visual comfort as the y-axis, as shown in **Figure 3**, and draw a scatter diagram in the X-Y coordinate system. From **Figure 3**, it can be seen that the changes of visual comfort of these 25 subjects are roughly divided into three stages: stable growth period, rapid growth period and slow growth period. With the increase of time t, visual comfort y almost cease to increase at first, then increases rapidly, and finally slows down. And the distribution of points is closer and closer to a straight line parallel to the x axis, so the y value will not increase infinitely.

According to the change law and trend line of visual comfort in the scatter diagram, it is found that the change trend line of visual comfort and time is approximately similar to the shape of S. The data is taken into Origin nonlinear fitting. Through comparison, it is concluded that when the fitting model is slogisticl1 S type function, the fitting degree is the highest, and the R square is 0.991. At this time, the equation is as the following.

$$y = \frac{a}{1 + e^{-k(x-xc)}} \tag{1}$$

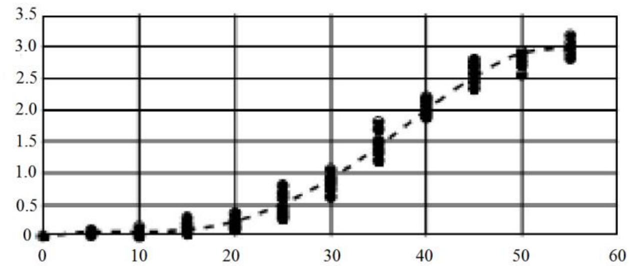

Figure 3. Relationship curve between test time and visual comfort.

The fitting curve is shown in **Figure 4**.

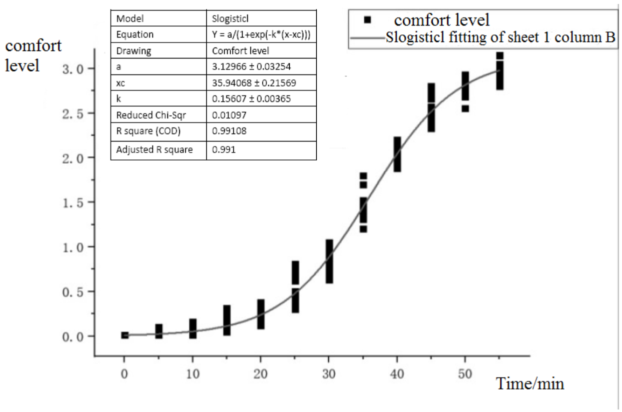

Figure 4. Fitting curve.

The parameters of the fitting equation: a = 3.12966, xc = 35.94068, k = 0.15607.

Therefore, the fitting equation is as the following.

$$y = \frac{3.12966}{1 + e^{-(0.15607\times(x-35.94068))}} \tag{2}$$

Formula (2) is the expression of the relationship between the visual comfort value y in information perception and the time variable x. The quantitative model of visual comfort has been established.

6. Mathematical Model Verification of Comfort Quantification

In order to verify the accuracy of the mathematical model, another five test experimenters were conducted under the same conditions. Compare the comfort degree of test data with the visual comfort degree obtained through the transformation of mathematical model relationship. See **Table 3** for validation data. **Figure 5** is the scatter diagram of the validation data compared with the relational curve. According to the verification data in **Table 3**, the mathematical model of visual comfort obtained from the original data in the test through the calculation of relational expression is basically fitted. Therefore, it can be verified that the whole process of measuring comfort data through test, analyzing the data, obtaining the mathematical model, and finally calculating the corresponding time through the mathematical model is correct.

Table 3. Model validation data time/min

	0	5	10	15	20	25	30	35	40	45	50	55
1	0.01	0.03	0.05	0.10	0.28	0.52	0.99	1.45	2.10	2.58	2.75	2.98
2	0.01	0.02	0.04	0.06	0.12	0.36	0.72	1.44	2.06	2.46	2.62	2.90
3	0.01	0.05	0.15	0.18	0.35	0.66	0.89	1.50	2.05	2.62	2.75	2.95
4	0.01	0.05	0.15	0.26	0.35	0.70	0.92	1.55	2.10	2.50	2.85	3.15
5	0.01	0.01	0.10	0.13	0.21	0.62	0.85	1.52	1.99	2.62	2.80	3.00
Calculated comfort value	0.01142	0.02482	0.05367	0.11479	0.24009	0.48036	0.88726	1.45017	2.04458	2.51743	2.81585	2.9776

7. Conclusion

A large number of experiments on the test objects are conducted, and the test data are imported into Origin software, drawing the change curve of visual comfort with reading time. The S-shaped curve is used as a reference for fitting, and the relationship between visual comfort and reading time is obtained, establishing the mathematical model of the relationship between reading time and visual comfort. The results show that the mathematical model can better reflect the objective law of visual comfort changing with reading time. The mathematical model can provide a theoretical basis for visual time allocation in design and production, making the product more humane in visual human-computer interaction and more in line with the design concept of "people-oriented". Of course, this part can also be used as a guiding scheme in the process of design and production, so the model owns important practical value.

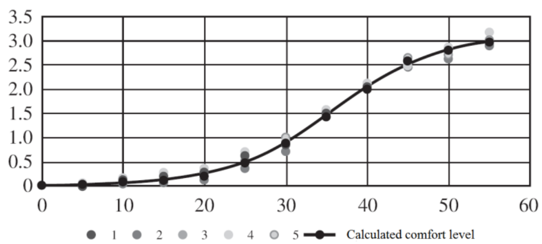

Figure 5. Scatter plot of validation data compared to relational curve.

Due to the complexity of human visual system and the diversity of influencing factors of visual comfort, the quantitative research of visual comfort must be a long-term and systematic process. This paper only studies the impact of reading time on visual comfort. Other influencing factors such as flicker, binocular brightness difference, binocular color difference, and individual physiological factors of human eyes, still need further research and exploration.

Conflict of interest

The authors declare that they have no conflict of interest.

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