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Research on the Construction of Information Visualization-Dynamic Chart

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Abstract. According to the current development direction in the field of information visualization, the dynamic chart is studied as the expression form of time series data, and the visualization model between data and people is established. By means of cognitive psychology, statistical analysis and eye tracking, this paper studies and analyzes the attention, memory and thinking of users in each stage of visual thinking activities at visual terminals, and explores the specific use environment, methods and standards of dynamic charts. Furthermore, it provides an effective reference for the research of information visualization in temporal data visualization and visualization effect evaluation.

1 Introduction

In 1989, Stuart K. Card, Jock D. Mackinlay and George G. Robertson first proposed the term "information visualization" in their article "Cognitive Coprocessor for Interactive User Interface"[1]. Information visualization attempts to make use of human visual ability to understand the meaning of abstract information, thus strengthening human cognitive activities. In this way, human beings with fixed perceptual ability can control the increasing amount of data.

The chart form of information visualization first appeared in the 18th century. Playfair, a historical and political scientist, and Lambert, a mathematician, first created visual charts. They believed that converting complex data into charts could help people understand data. Minard and Marey, French scientists in the 19th century, drew charts for the first time by non-manual methods [2]. In the 21st century, with the rapid development of big data technology and network transmission technology, the way of transmitting information through paper media is no longer applicable. Mobile terminals with dynamic display of charts and wireless transmission have become new information carriers. The dynamic research of charts has also become one of the research hotspots in the field of "information visualization".

"Dynamic Chart" can compare the time series in the data with the actual time, and formulate the order of chart information according to the passage of the time line, which is an extension of the information chart to the space-time dimension. Based on the characteristics of dynamic charts, scholars at home and abroad have summarized the advantages of many such visualization methods[3]. First, the timeline of the dynamic chart can carry one-dimensional data, allowing this kind of method to have more data capacity. For example, a bivariate three-attribute data set containing the changes in the occupancy prices of various types of rooms in a hotel over 10 years (assuming that the hotel adjusts the room prices for a period of 1 year), We can use the expression method of "dynamic chart" to draw the room type and check-in price into a traditional column chart with single variable and double attributes, use 1S of real time as a frame to mark the room price column chart of the hotel within one year, and play the chart 10S to achieve the expression effect[4]. Second, the dynamic vision in the information chart does not simply superimpose the data in the static chart. On the principle of following the visual rule, the "dynamic chart" can place the n-1 dimension of the n-dimensional data in the priority of the user's browsing order (here 1 refers to the one-dimensional data on the timeline), thus playing a guiding role in information reading. At the same time, because dynamic vision will affect users' attention, dynamic charts may be better than individual relationships in the expression of overall data relationships[5]. Third, dynamic charts can generate interactive control between data and people, allowing users to freely select a single frame to call data. Completing memory loopholes through subjective selective learning. Therefore, compared with traditional static charts, "dynamic charts" have higher dimensional bearing capacity and certain cognitive advantages [6].

However, scholars at home and abroad basically adopt the methods of literature research and case analysis in the research of dynamic chart cognitive style. Although there has been some progress in breadth, there is a lack of qualitative and quantitative experimental methods to test the specific characteristics of the visualization method of "dynamic chart" [7]. Therefore, there are still many vague definitions of its presentation mode, information characteristics and cognitive efficiency. In the face of visual confusion, cognitive load and other problems of

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dynamic charts, information designers often follow experience and cannot obtain effective references. Therefore, it is of both academic value and practical significance to visually evaluate and analyze dynamic charts through empirical research.

2 Experimental Design and Overview

In this paper, the memory processing theory of cognitive psychology will be used to import objective data into different visual models for comparative experiments through statistical analysis and eye tracking. Summarize and analyze the effectiveness and emphasis of users in attention, memory and thinking, and explore the specific use environment, methods and standards of "dynamic chart" visualization. There are two rounds of experiments. The first round of experiments compares the cognitive differences between static and dynamic column charts, and the second round compares the cognitive differences between interactive and non-interactive dynamic column charts.

In order to narrow the scope of the experiment, the column chart is used as the experimental sample in this experiment. As the most commonly used chart in statistics, column chart is ubiquitous in people's daily life and study, so it has certain representativeness in the application field of dynamic chart[8].

3 Specific application of experimental means

3.1 Cognitive Psychology

According to the cognitive principle of cognitive psychology, because the experiment in this paper involves certain language and data information, when the same group of subjects is used for the experiment, the testers will have significant delay effect in the comparison between groups, which will affect the test results of the second group after interacting with the first group of test data. The tester may be affected by learning effect or fatigue problem and change the observation mode, learning mode and cognitive effect in the second group of test experiments. Therefore, in order to reduce the experimental error, this test will adopt the inter-subject design.

In cognitive psychology, memory is divided into working memory (instant memory) and long-term memory according to different degrees of cognitive processing. Due to the need for long-term memory to process information finely, accurate measurement cannot be carried out. Therefore, the questionnaire formulation of this experiment follows the characteristics of memory processing, and the topic types of the test questionnaire are divided into fuzzy relation category (D), relation location category (E) and unit value category (F) according to the scope of working memory [9]. The specific processing process is shown in Figure 1.

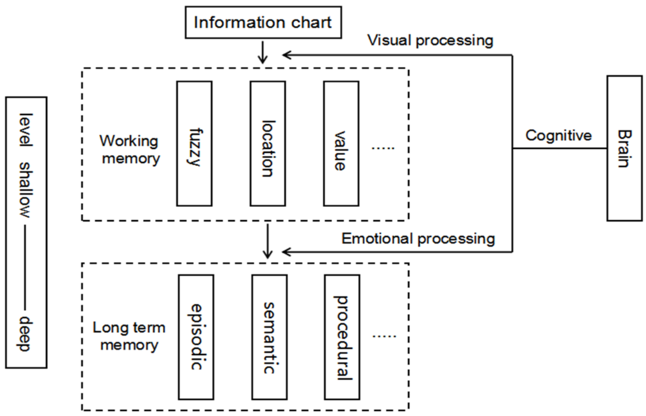

Figure 1. Memory processing

3.2 Eye tracking technology

According to research, the movement of the eye can reflect the purpose and mode of the user's visual search. By examining the data such as the fixation time, beating mode and speed of the eye during eye movement, it is helpful to reveal the processing mechanism of cognitive psychology and the selection mode of visual information.

3.3 *Statistical analysis*

In this experiment, the average value of the two groups of test results is compared and analyzed, and the independent sample T test is carried out according to the normal distribution and variance homogeneity of the data and combined with preliminary analysis. According to the P (double tail) value, judge whether there is a significant difference between the average values of the two groups of tests, and then draw a conclusion through analysis[10].

4 Experimental hypothesis

On the premise of the same reading time and the same information carrying capacity of the chart model, the following assumptions are put forward according to the fixed chart playing rate and reading materials in this experiment:

(1) Compared with static column chart, dynamic column chart has higher total information acquisition.

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(2) Dynamic column chart plays a guiding role in reading information with time series as the carrier.

(3) The dynamic column chart will miss some contents in the process of information guidance.

(4) Compared with non-interactive dynamic column charts, interactive dynamic column charts have higher total information acquisition.

(5) Compared with non-interactive dynamic column chart, interactive dynamic column chart will secondary learn missing information and reduce cognitive load.

5 Experimental Procedures

5.1 Subject Selection

In order to reduce the difference between the congenital cognitive level and vision level of the subjects, 30 graduate students with similar age and subject background were selected as the subjects in this experiment. All subjects had uncorrected or corrected visual acuity above 1.0, no symptoms of color blindness and weakness, good health, and no astigmatism or blindness.

5.2 Fabrication of test materials

This experiment requires two sets of objective data. The statistical data of various meat production in Lianjiang County and Minhou County of Fujian Province from 2014 to 2018 (the data come from the statistical bulletin of national economic and social development of county-level units in Fujian Province) are respectively selected to produce and generate two sets of column charts H and R. Among them, H_1 and H_2 adopt the statistical data of Lianjiang County, while R_1 and R_2 adopt the statistical data system of Minhou County. H_1 is a static column chart, the relationship between meat and output is taken as the conventional coordinate, and the year is distinguished by color and marked additionally. H_2, R_1 and R_2 are dynamic column charts, the relationship between meat and output is taken as the conventional coordinate, and one frame picture is used to mark the static column charts of each meat output in one year. Among them, R_1 is equipped with interactive keys, which can call each frame separately. In order to reduce the experimental error, the column charts in the two groups of models are marked with the same size and font size(As shown in the figure 2) .

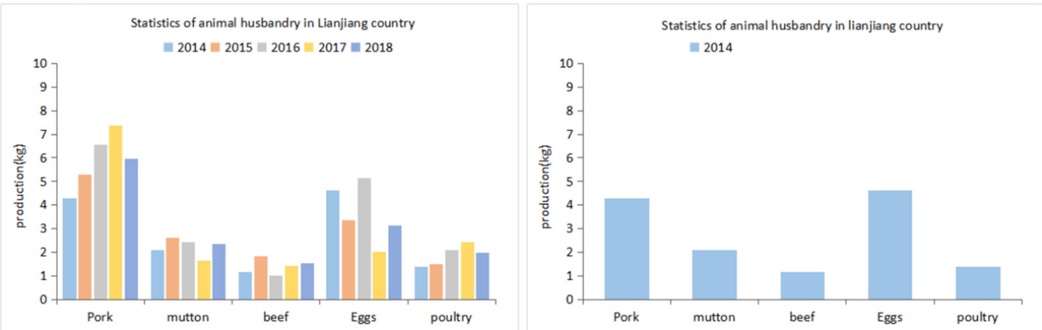


Figure 2. Test materials H_1 and H_2

5.3 Preparation of Test Questionnaire and Formulation of Score Items

The types of questions in the test questionnaire are divided into fuzzy relation category (D), relation location category (E) and unit value category (F) based on the basic information types remembered by users after reading the charts. The number of topics is determined according to the data dimension and attribute analysis of the experimental chart (in principle, the numerical memory, single logical relationship and overall logical relationship of each element in the data must be included).

Note: This basic information refers to the cognitive processing of users in working memory (working memory is a short and immediate memory of a limited amount of materials currently processed). Due to the different order of the subjects' filling and reading the questionnaire questions, the working memory will be lost to different degrees, so the design of the questionnaire should minimize the answering time. Therefore, this experiment uses the questionnaire form to fill in, and makes score statistics according to the following topic types.

The fuzzy relation class (D) has 40 topics and is divided into two groups. The size relation of every two adjacent elements in the same attribute is 1. Group (D_1) is a topic describing the relationship between year and output (for example, has the pork output in 2016 increased or decreased compared with last year?) . Group (D_2) is a topic describing the relationship between meat and output (for example, is the pork output more or less than mutton output in 2015?).

There are 50 questions in the relation positioning class (E) and they are divided into two groups, and the intra-group size relation of each element in the same attribute is 1. Group (E_1) is a topic describing the relationship between year and output (for example, what is the ranking of pork output in 2018 in five years?). Group (E_2) is a topic describing the relationship between meat and production (for example, what is the ranking of beef production in 2017?).

There are 25 questions in the unit numerical category (F), and the numerical memory of each element is 1 (for example, which of the following intervals is the mutton output in 2016?).

According to the above 115 questions, the test questionnaire makes score statistics, with 1 point for each question answered correctly and 0 point for each question answered incorrectly (As shown in the figure 3).

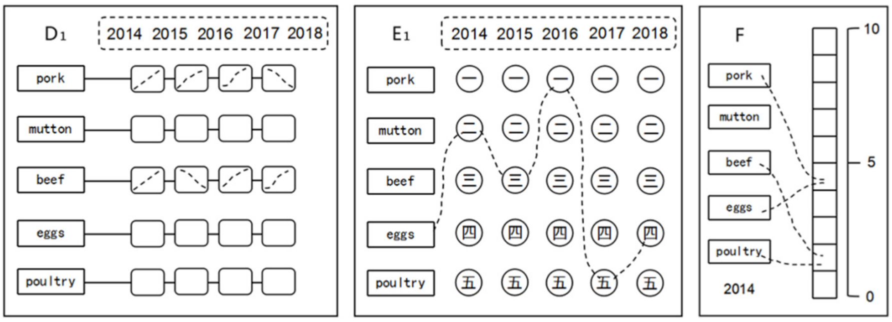


Figure 3. Questionnaire Test Tables

5.4 Experimental Process

The experimental site is the Eye Movement Laboratory of the School of Mechanical Engineering of Guizhou University. A total of two rounds of comparative tests were carried out in the experiment. Each round of experiments lasts for one day. In order to ensure that the experiment is carried out in a relatively quiet environment, the waiting phase, experiment and questionnaire filling phase of the experiment will be arranged in two different areas.

The experiment time takes one minute as a cycle, the first 20S is used to read charts (the selection and playing modes of reading materials are shown in Table1), and the second 40S is used to fill in questionnaires. A total of 10 cycles (the type and sequence of questions for each answer are shown in Table2). The total time is 10 minutes (the answer time is determined according to the online questionnaire pre-test to ensure that the full marks and failure of each item are less than 5% of the total number of subjects).

TABLE 1. SELECTION AND PLAY OF READING MATERIALS

			Readings				Play mode	
ROUNDS	group	Number	Name	Type	Interaction	Fps	First 10s	Late 10s
ONE	A1	15	H1	Static	No			
	B1	15	H2	Dynamic	No	0.5/s	Play	Play
TWO	A2	15	R1	Dynamic	Yes	0.5/s	Play	Interaction
	B2	15	R2	Dynamic	No	0.5/s	Play	Play

Before the start of the experimental test, the subjects will be required to learn the expression mode of dynamic charts five minutes in advance to balance the familiarity of the subjects with the two charts.

Eye movement tracking will be carried out simultaneously during the reading phase of the experiment. Before reading, the experimenter will proofread the subjects' eyeball coordinates. After the coordinate proofreading is completed, the subjects will be prompted, "What you are going to see is a set of data column charts. Please remember so-and-so type of information (e.g. XXX) in the chart according to your daily reading habits. You will have 20S reading time, and please do not leave the screen during reading. After reading, you will fill in the answer for 40S."

TABLE 2. TIME AND PHASE OF EXPERIMENT

EXPERIMENTAL STAGES	Map recognition	Fill in a form	cycles
ONE STAGE (D)	20s	40s	4
TWO STAGES (E)	20s	40s	4
THREE STAGES (F)	20s	40s	2
TOTAL	3mins20s	6mins40s	10

After reading, the subjects will enter the answer area and fill in the questionnaire according to the memorized icon information. After all the subjects have filled in, the experimenter will count and classify the contents according to the scores, and finally import the score data into SPSS software for analysis.

6 Questionnaire Analysis

6.1 First Round

Mean Analysis of First Round of Experimental (As shown in Table 3);

(1) The average scores of group A (D, E, F) were lower than those of group B.

(2) The average scores of items D and E in group A are lower than those in group B, while the average scores of items F are higher than those in group B.

(3) The value in group A (D1/D2) was lower than that in group B.

(4) The value of E1/E2 in group A was lower than that in group B.

Table 3. The first round of experimental group statistics

	Group	Sample	Mean value	deviation	Average standard error
D	A1	15	28.93	3.105	0.802
	B1	15	31.80	3.802	0.982
E	A1	15	33.20	3.234	0.835
	B1	15	36.07	3.674	0.949
F	A1	15	21.47	2.748	0.710
	B1	15	19.07	3.150	0.813
(D, E, F)	A1	15	83.60	6.412	1.656
	B1	15	86.73	8.405	2.710
D1/D2	A1	15	0.970	0.212	0.054
	B1	15	1.159	0.272	0.070
E1/E2	A1	15	1.025	0.262	0.068
	B1	15	1.174	0.273	0.070

Significance Analysis of Differences in the First Round of Experimental (As shown in Table 4);

(1) There was no significant difference in the total scores of D, E and F between group A and group B ($p > 0.05$).

(2) There were significant differences in the scores of D, Eand F between group A and group B ($p < 0.05$).

(3) There was significant difference between group A and group B (D1/D2) ($p < 0.05$).

(4) There was no significant difference between group A and group B (E1/E2) ($p < 0.05$).

Table 4. Independent Sample T Test in the First Round of Experiments

		Levene		T Test of Mean Equation						
								Std. Error	95% confidence	
		F	Sig	T	Df	Sig.	Mean Diff	Diff	Lower	Upper
D	Equal f	1.335	0.258	-2.262	28	0.032	-2.867	1.267	-5.463	-0.270
	Not equal			-2.262	26.92	0.032	-2.867	1.267	-5.468	-0.266
E	Equal f	0.121	0.730	-2.269	28	0.031	-2.867	1.264	-5.455	-0.278
	Not equalt			-2.269	27.55	0.031	-2.867	1.264	-5.457	-0.276
F	Equal f	0.042	0.840	2.223	28	0.034	2.400	1.079	0.189	4.611
	Not equalt			2.223	27.49	0.035	2.400	1.079	0.187	4.613
(D, E, F)	Equal f	2.394	0.133	1.148	28	0.261	3.133	2.729	-2.458	8.724
	Not equalt			1.148	26.17	0.261	3.133	2.729	-2.475	8.742
D1/D2	Equal f	0.646	0.428	2.119	28	0.043	0.188	0.089	0.006	0.372
	Not equal			2.119	26.42	0.044	0.188	0.089	0.006	0.371
E1/E2	Equal f	0.004	0.951	1.529	28	0.138	0.149	0.097	-0.052	0.349
	Not equal			1.529	27.95	0.138	0.149	0.097	-0.052	0.349

6.2 Second Round

Mean Analysis of the Second Round of Experimental (As shown in Table 5);

(1) The average scores of D, E and F in group A were higher than those in group B.

(2) The results of item F in group A are higher than those in group B.

Table 5. The second round of experimental group statistics

	Group	Sample	Mean value	deviation	Average standard error
(D, E, F)	A2	15	88.67	6.230	1.609
	B2	15	83.93	6.100	1.575
F	A2	15	21.67	2.554	0.659
	B2	15	18.87	3.091	0.798

Significance Analysis of Differences in the Second Round of Experimental (As shown in Table 6);

(3) There were significant differences in the total scores of D, E and F between group A and group B (p <

0.05).

(4) There was significant difference between group A and group B in the results of F ($p < 0.05$)

Table 6. Independent Sample T Test in the Second Round of Experiments

		Levene		T Test of Mean Equation						
								Std. Error	95% confidence	
		F	Sig	T	Df	Sig.	Mean Diff	Diff	Lower	Upper
(D, E, F)	Equal f	0.170	0.683	2.103	28	0.045	4.733	2.251	0.122	9.345
	Not equal			2.103	27.98	0.045	4.733	2.251	0.122	9.345
F	Equal f	0.725	0.402	2.705	28	0.012	2.800	1.035	0.679	4.921
	Not equal			2.705	27.04	0.012	2.800	1.035	0.676	4.924

6.3 Summary of Questionnaire Analysis

In the cognitive comparative analysis of static and dynamic charts, we found that there was no significant difference in the total information acquisition between dynamic charts and static charts. Dynamic charts have advantages in information cognition of fuzzy relation class D and relation location class E. Static charts have advantages in information cognition of unit numerical class F. In the cognition of time series information, dynamic chart has some advantages, but it is not obvious.

In the cognitive comparative analysis of interactive and non-interactive dynamic charts, we find that interactive dynamic charts have significant differences in the acquisition of total information. In the information cognition of unit numerical class F, interactive dynamic charts have advantages.

7 Eye Movement Analysis

7.1 Eye Movement Visual Behavior Analysis

In order to facilitate the analysis and summary of eye movement data, according to the processing characteristics of visual cognition, we divided the intuitive information types in the reading chart into fixation areas according to the following figure (As shown in the figure 4):

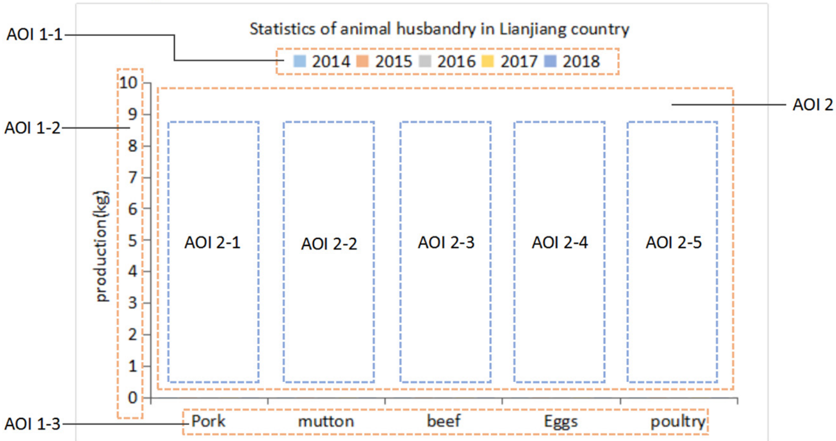


Figure 4. Visual region division

According to the gaze area in the above figure, we can summarize the following two ways of eye beating in visual search (As shown in the figure 5). We will compare the fixation time length and saccade frequency of each fixation area in different charts for subsequent eye movement data analysis.

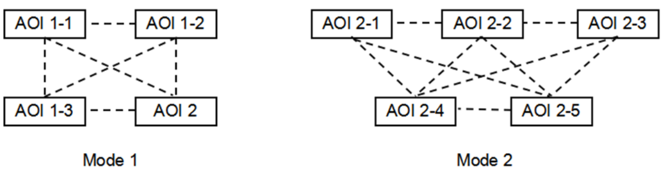
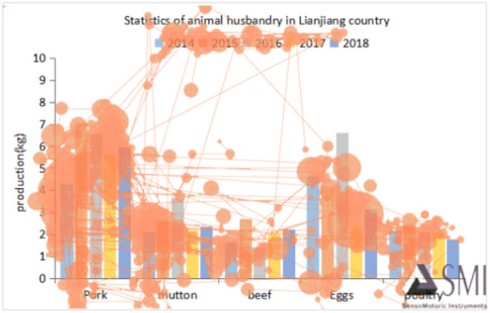


Figure 5. Saccade mode

7.2 Hotspot map analysis

According to the hot spot map, we speculate that there is a certain correlation between fixation time, saccade times and cognitive level in different regions. In information types (D, E), AOI2 fixation time is much longer than other fixation regions. The number of saccades in mode 2 is greater than that in mode 1. In information type F, the number of saccades in mode 1 is greater than that in mode 2(As shown in the figure 6).



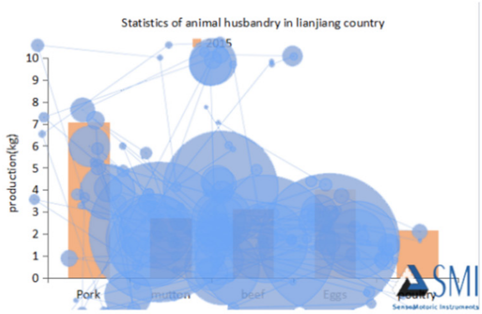


Figure 6. Hot spot map

7.3 Analysis of the First Round of Experimental Data

In terms of fixation time: In information types (D, E, F), AOI2 has much longer fixation time than other fixation areas. The fixation time of group B was longer than that of group A. In the information type (D, E), the fixation time of AOI2 was longer than that of F. In information type F, the fixation time of AOI1-2 is much longer than that of other information types. The fixation time of group A was longer than that of group B.

In terms of saccade times: in information type F, the average saccade times of mode 1 are much higher than those of other information types. The average saccade frequency in group A was higher than that in group B (As shown in Table 7).

TABLE 7. FIRST ROUND OF EYE MOVEMENT EXPERIMENT

ROUNDS	Group	Percentage of fixation time (%)				Saccade per second	
		AOI 1-1	AOI 1-2	AOI 1-3	AOI 2	Mode 1	Mode 2
D	A1	7.2	4.1	6.4	28.5	0.26	0.67
	B1	8.1	3.4	6.5	30.9	0.23	0.79
E	A1	6.6	3.6	12.1	27.1	0.29	0.71
	B1	8.3	4.7	8.7	28.7	0.24	0.79
F	A1	6.9	13.5	11.5	24.3	0.83	0.38
	B1	5.7	9.4	7.1	26.1	0.67	0.43

7.4 Analysis of the Second Round of Experimental Data

In terms of fixation time: In information types (D, E), AOI2 has more fixation time than F. In information type F, the fixation time of AOI1-2 is much longer than that of other information types. The fixation time of group A was longer than that of group B.

In terms of saccade times: in information type F, the average saccade times of mode 1 are much higher than those of other information types. The average saccade frequency in group A was higher than that in group B(As shown in Table 8).

TABLE 8. SECOND ROUND OF EYE MOVEMENT EXPERIMENT

ROUNDS	Group	Percentage of fixation time (%)				Saccade per second	
		AOI1-1	AOI 1-2	AOI 1-3	AOI 2	Mode 1	Mode 2
D	A1	6.9	3.3	7.7	31.7	0.34	0.52
	B1	7.3	2.8	8.5	30.3	0.21	0.81
E	A1	6.7	3.5	9.4	26.2	0.38	0.49
	B1	8.4	2.7	10.1	29.4	0.23	0.78
F	A1	5.2	14.6	11.2	23.6	0.96	0.36
	B1	6.7	11.4	8.1	25.1	0.64	0.49

7.5 Summary of eye movement analysis

By observing the fixation time of each fixation region and the frequency of eye-to-eye beats between regions, combined with the results of questionnaire analysis, we found that in fuzzy relation class (D) and relation location class (E), charts that can focus on AOI2 region have better cognitive efficiency. In the cell numerical class (F), charts that can make the visual focus jump more between AOI1-2 and AOI2 regions have better cognitive efficiency. This may be because there is more inter-group relationship information in AOI2 region and more numerical information in AOI1-2 region.

8 Conclusions

Based on the analysis results of the questionnaire test and eye movement experiment, the study confirmed the assumptions of experimental hypotheses 2, 3, 4 and 5. The experimental results are as follows: (1) Dynamic column chart can guide users to read the information on the time series preferentially through playing. (2) The dynamic column chart will omit the reading of incoherent data during the playing process. (3) The interactive dynamic column chart can learn the missing information twice and also has a certain guiding effect. Therefore, it has better cognitive efficiency.

The next experiment will consider extracting and summarizing the same element features of various tables when performing dynamic performance to carry out experiments, thus providing applicability. The method of replacing data link with specific symbols is used to reduce the experimental error. This experiment is only a visual cognitive study on the dynamics of column charts, which cannot reflect the performance rules of all dynamic charts. Therefore, the applicability of the conclusion is affected to some extent. As a result, the number of testers is limited and the dynamic column chart at various playback rates cannot be studied, so the research arguments related to cognitive load cannot be clearly defined. Although the production of reading materials has been uniformly designed and labeled. However, the impact of data structure cannot be avoided.

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