東　海　大　學

統計學系碩士班

碩士論文

RSVP 與圖形呈現對於行動設備之視覺績效評估研究

Effects of RSVP and Graphical Displays on the Visual Performance of Mobile Devices

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Abstract

In this study, we focus on the effects of types of graphical display and modes of rapid serial visual presentation (RSVP) interface on the visual performance of quantitative data on the small screen devices. Three types of graphical displays, including line graph, bar graph, and map, and five modes of RSVP interfaces, including carousel mode, collage mode, shelf mode, keyhole mode, and convention mode will be considered as the design factors. The objective is to evaluate the optimal visualization interface of quantitative data on a small screen. Graphical perception tasks are including reading the exact value, identifying the trend, comparing two values, and reading the maximum value. Two factorial experiments with blocks were applied to Experiment 1 (twenty-four participants) and Experiment 2 (thirty-six participants). The results of Experiments 1 and 2 show that both the interaction of RSVP and graphical display types as well as the interaction of graphical perception tasks and graphical display types are statistically significant. For the tasks of reading the exact value and identifying the trend, line and bar charts are significantly better than map for any kind of RSVP designs. For the comparing two values, the collage-map, shelf-map, convention-map, carousel-bar, and keyhole-bar designs have the relatively smaller mean response times. It should not be recommended for collage-line design for comparing values. For the reading the maximum value, carousel-bar, keyhole-bar, and keyhole-line designs are worthy of recommendation but keyhole-map design is not recommended for the small screens.

Keywords: Rapid Serial Visual Presentation (RSVP) Interface, Small Screen Devices, Graphical Perception, Quantitative information Extraction

中文摘要

本研究欲探討圖形呈現與 RSVP 圖形資料界面應用在小螢幕設備上的量化視覺績效效果。三種圖形呈現媒介--分為折線圖（line graph）、長條圖（bar graph）、與地圖（map）和五種 RSVP 圖形資料界面包括：旋轉木馬型（carousel）、拼貼型（collage）、物架型（shelf）、孔洞型（keyhole）與傳統型縮圖（convention）。研究目的為在小螢幕上評估理想的量化資料介面。圖形認知任務包含精確判斷、識別趨勢、兩點比較和極值判定。實驗一（24 名受試者）與實驗二（36 名受試者）均採行三因子區集實驗設計，透過實驗的方式搜集相關之數位訊息解碼績效。實驗一與實驗二的結果均顯示 RSVP 與圖形呈現的交互作用項與圖形呈現與圖形認知任務的交互作用項的效果均為顯著的。對於精確判斷與識別趨勢的任務而言，在任何一種 RSVP 設計下，折線圖與長條圖均顯著的比地圖來的好。對於兩點比較任務而言，拼貼型-地圖、物架型-地圖、傳統型-地圖、旋轉木馬型-長條圖與孔洞型-長條圖的組合設計有較短的平均反應時間。對於拼貼型-折線圖的組合設計在兩點比較任務是不被推薦的。對於極值判定任務而言，旋轉木馬型-長條圖、孔洞型-長條圖與孔洞型-折線圖是值得被推薦的組合設計，然而，孔洞型-地圖則是在小螢幕不被推薦的組合設計。

關鍵詞：RSVP 界面、小螢幕設備、圖形認知、數位訊息擷取

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1. INTRODUCTION

1.1 Motivation

Studies in graphical perception, both theoretical and experimental, provide a scientific foundation for the construction of statistical graphics. A summary was given by Chapman (1986). Do we need any further guidance? Surely the answer is “yes”. Cleveland and McGill (1987) proposed a general discussion of graphical perception. Three areas of statistical graphics are delineated-computing, methodology, and construction. Graphical perception provides fundamental importance for the construction area because its study provides a scientific foundation for many issues that arise in graph construction. An important trend in the area of statistical graphics is graphical methods for data analysis. A particularly promising part of this area is dynamic, high-interaction graphical methods (Becker, Cleveland, and Wilks, 1986) in which a data analyst interacts with a display of data on a computer graphics screen through the use of a control device such as a mouse. The details of construction of a graph determine what visual process we must employ to decode the information. The construction is successful only if our visual systems perform this graphical perception with accuracy and efficiency.

Forster (1970) first used Rapid Serial Visual Presentation (RSVP) to mean rapidly displaying words in a sequence in the same visual location. RSVP originated as a tool for studying reading behavior (Forster, 1970; Juola et al., 1982; Potter, 1984), but lately has received more attention as a presentation technique with a promise of optimizing reading efficiency, especially when screen space is limited (Goldstein et al., 2001; Juola et al., 1995; Muter, 1996; Rahman and Muter, 1999; Sicheritz, 2000). The reason for the interest is that the process of reading works a little different when

RSVP is used and that it requires much smaller screen space than traditional text presentation (Öquist and Goldstein, 2003). Their research suggested that Adaptive RSVP decreased task load ratings for most factors comparing to Fixed RSVP.

As the quick development of wireless communication and mobile devices, the challenge of finding ways to present quantitative information on small screen devices becomes increasingly urgent. Can readability of statistical graphs on small screen devices be improved by using RSVP than convention mode? The possible impact of design decisions on the ability of users to effectively perceive the displayed content for quantitative data is our particular concern. Convention mode and four modes of RSVP (De Bruijn & Spence, 2002) are briefly summarized and illustrated as Figure 1 below:

Convention mode

This approach displays a grid of thumbnailed pictures and allowed the same size of the thumbnails to show on screen at one time.

Keyhole RSVP

In the keyhole mode, only one image is visible at any moment in time and all the images appear in the same location at the same size.

Carousel RSVP

In the carousel mode, each image describes an approximately circular trajectory from its emergence at small size, increasing to maximum area at the top of the circle and then reducing again until 'reentering' the folder from which it emerged.

Collage RSVP

In the collage mode, a set of images was deposited, in rapid sequence, on a table top in such a way that six are visible at any one time. Subsequent images will inevitable 'cover up' preceding ones.

Shelf RSVP

In the shelf mode, a set of images was displayed in catalogue pages for immediate viewing.

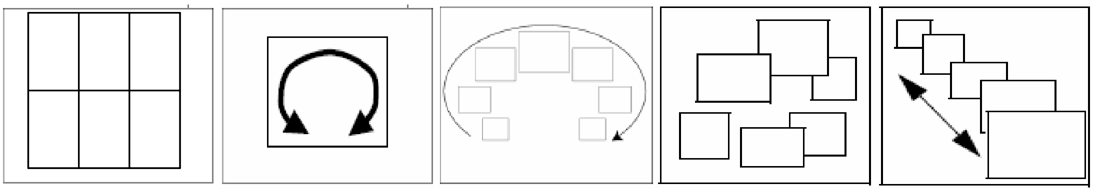


Figure 1 RSVP modes from left to right: convention, keyhole, carousel, collage, and shelf. The circular arrow within an image frame (as in keyhole mode) indicates replacement rather than movement.

1.2 Objectives

Applying the RSVP principles, we construct a visual interface design of statistical graphics on the small screen devices. In this study, the use of RSVP interfaces provides a rich set of multiple-objects information on the small screen devices. Three types of graphical displays, including line graph, bar graph, and map, and five modes of RSVP interfaces, including carousel mode, collage mode, shelf mode, keyhole mode, and convention mode will be considered as the design factors. The researcher's hypotheses proposed below will be discussed in terms of two experiments. Does the interaction of RSVP modes and graphical display types influence the visual decoding performance of quantitative information on the small screen devices for the four tasks —reading an exact value, comparing two values, reading the maximum value, and identifying the trend? The objective is to evaluate the optimal visualization interface of quantitative data on a small screen device. We will try to propose the designing guidelines of statistical graphs by using RSVP interfaces on the small screen devices, especially on the mobile devices.

1.3 Research Framework

The procedure of this research is as follows: (1) introduction; (2) literature review; (3) research methodology; (4) results and discussion; (5) conclusion. In introduction, the motivation and the objections are described. In literature review, information-processing analysis of graphical perception, RSVP techniques for multiple objects display and RSVP application to small screen devices are reviewed. The preliminary preparation—contextual inquiry and the experiments 1 and 2 are described in the research methodology. The results and discussion will show basic descriptive statistics, proposed models, results of analysis of variance, and discussions. Finally, the limitations of experiment and the further research are described in the conclusion.

2. LITERATURE REVIEW

In this chapter, some literatures would be reviewed including (1) information-processing analysis of graphical perception, (2) RSVP techniques for multiple objects display and (3) RSVP application to small screen devices.

2.1 Information-Processing Analysis of Graphical Perception

There are several lists of elementary perceptual processes that provide vocabularies with writing algorithms to account for performance in simple graph-perception tasks. Cleveland and McGill (1984) had developed a paradigm for graphical perception that began with the isolation of elementary codes of graphs. These codes are ordered based on how accurately people perform them. The following are the 10 elementary codes ordered from most to least accurate: (1) Position along a common scale (2) Positions along nonaligned scales (3) Length, direction, angle (4) Area (5) Volume, curvature (6) Shading, color saturation. These are fundamental geometric, color, and textural aspects that encode the quantitative information on a graph. The judgments of the codes make up the rapid processing when we perform to the extract information visually about the relative magnitudes of quantities shown on the graph. Judging position is a task used to extract the values of the data in the bar chart. But the graphical elements used to portray the data—the bars—also change in length and area. We conjecture that the primary elementary task is judging position along a common scale, but judgments of area and length probably also play a role. Line graphs and bar charts are isomorphic—that is, each element in one display corresponds to only one element in another display. Statistical maps those use shading (or color saturation or color hue) to encode a real variable, which Tukey

(1979) called patch maps, are commonly used for portraying measurements as a function of geographical location. To judge the values of a real variable encoded on a patch map with shading, one must perform the elementary perceptual task of judging shading, which is at the bottom of our perceptual hierarchy. In this study, we will assess the relative efficiency of line graphs, bar charts, and statistical maps.

Furthermore, let’s discuss the general principles of graph construction in a broader context. A summary was given by Chapman (1986). Some apparently simple rules are as follows: (1) Graphs should have a clear self-explanatory title. Units of measurement should be stated. All axes should be labelled. (2) The scales on each axis need to be carefully chosen so as to avoid distorting or suppressing information. (3) The mode of presentation needs to be chosen carefully. This includes the plotting symbol and the method of connecting points. (4) Trial-and-error can be used to improve a graph. Statistical graphics was a newly activated area of statistics because of the computer graphics revolution. High-quality hardware systems are available at low cost for generating graphs by computer. Cleveland and McGill (1987) proposed a general discussion of graphical perception. Three areas of statistical graphics are delineated-computing, methodology, and construction. An important trend in the computing area has been a movement away from batch processing on mainframes toward highly interactive graph production on personal workstations. Research on interactive principles for statistical graphics can be categorized into two classes. Firstly, development of innovative tools that help making a single display flexible and dynamic, for example, interactive modifiers of the bar width of a histogram, zooming in sot or scatter plots as well as slider-controlled dynamic changes in a graphic. Secondly, development of tools that operate in the underlying data and therefore have impacts on all displays showing the same data.

Graphical methods for data analysis consist of a choice of certain quantitative information shown on a graph help the analyst to understand the data or the performance or properties of a statistical model fit the data. Dynamic, high-interaction graphical method was a particularly promising part in which a data analyst interacts with a display of data on a computer graphics screen through the use of a control device such as a mouse. Having decided what quantitative information is useful to display, one needs to construct a graph. This is graph construction of statistical graphics. To decide what geometric aspects of the graph will encode the quantitative information, one can choose the scales, the shape parameter, and so forth.

Meyer et al. (1997) assessed the relative efficiency of line graphs, bar graphs, and tables, studied the effects of the type of the required information, the complexity of the data, and the user's familiarity with the display. Five tasks used in their experiments represent a variety of common information extraction tasks: (1) reading the exact value of a single point; (2) comparing two points that belong to the same data series but that have different values on the x axis; (3) comparing two points that have the same value on the x axis but that belong to different data series; (4) identifying the trend of a data series; and (5) identifying the highest value from a specific data series.

2.2 RSVP Techniques for Multiple Objects Display

RSVP originated as a tool for studying reading behavior, but lately has received more attention as a presentation technique with a promise of optimizing reading efficiency. Attention to specific size is highly effective when RSVP stimuli are presented in single location at fixation point, and may be possible with stimuli in a few (2–4) locations. Mainly the distracting effects of rapid onsets of task-irrelevant stimuli can explain the difficulties of size-based visual selection with RSVP stimuli in multiple locations. When the overlapping small and large characters are presented without salient onsets, then selection by size is effective at least over six locations positioned in the circular array around fixation point, without any indication of decline at larger number of locations (Poder, 2001).

However, applications of RSVP may generally provide useful tools for the presentation of large numbers of loosely structured alternatives that can be adequately represented by image previews. De Bruijn and Spence (2002) concentrated on the impact of design decisions underlying a number of existing applications, of represented a different mode of RSVP modes. They also compared the effectiveness of carousel and keyhole RSVP. Subjects looked at a target image as long as they wished. They were shown a RSVP display of 20 images and asked if the target image had been displayed in this set of 20 images. Each participant performed the task seven times with both keyhole and carousel RSVP. When carousel RSVP was used, subjects could accurately report the presence of the target image with presentation times as low as 100 milliseconds. When keyhole RSVP was used, the target image was reported accurately when images were displayed for as little as 40 milliseconds.

An RSVP mode is the term given to a specific implementation of the RSVP process. RSVP modes include keyhole, carousel, collage floating and shelf. Each of these modes rapidly displays a series of images or text (Spence, 2002). We will discuss four RSVP modes (keyhole, carousel, collage and shelf) and one convention mode.

2.3 RSVP Application to Small Screen Devices

Much of the research undertaken in RSVP has focused on its application to small screen devices. Rahman and Muter (1999) suggested 4 ways of presenting text in a small display window as follows: (1) Though RSVP is disliked by readers, the present methods of allowing self-pacing and regressions in RSVP are efficient and feasible, unlike earlier tested methods ; (2) slower reading in RSVP should be achieved by increasing pauses between sentences or by repeating sentences, not by decreasing the presentation rate within a sentence; (3) completion meters do not interfere with performance and are usually preferred; (4) the space-saving sentence-by-sentence format is as efficient and preferable as the normal page format. They reported no significant differences in concerning comprehension and reading speed between statically presented text on screen and two RSVP formats. Output device in these experiments was a 15–inch CRT screen. The two RSVP formats were used either alone or with a completion meter. Participants were instructed to read as quickly and accurately as possible. The RSVP formats required the participants to press a key to proceed the next sentence. One passage of text, averaging 400 words, was used in each of the five conditions. The tests were preceded by practice sessions reading about 1200 words in each condition. All subjects performed in all conditions. The results showed no significant differences in regarding comprehension and reading speed.

De Bruijn et al. (2002) illustrated the use of space-time trade-off for information presentation on small screens. They proposed the use of RSVP provided a rich set of navigational information for Web browsing. The principle of RSVP browsing is applied to the development of a Web browser for small screen devices, the RSVP browser. They concluded that RSVP browsing as presented in the RSVP browser can be effectively applied to Web browsing on small screens. They studied several RSVP modes including carousel, floating and collage. They found that none of the modes posed any perceptual problem to the user. However, they did suggest that the modes that use moving images, such as carousel and floating, might cause more eye strain than modes that present static images, such as keyhole and collage.

Can readability on small screens be improved by using adaptive RSVP that adapts the presentation speed to the characteristics of the text instead of keeping it fixed? Öquist and Goldstein (2003) introduced Adaptive RSVP, described the design of a prototype on a mobile device, and reported findings from a usable evaluation where the ability to read long and short texts was assessed. The Adaptive RSVP attempts to mimic the reader's cognitive text processing pace more adequately by adjusting each text chunk exposure time in respect to the text appearing in the RSVP text presentation window. The Fixed RSVP means that the exposure times have generally been fixed. Their research suggested Adaptive RSVP decreased task load ratings for most factors compared to Fixed RSVP.

3. RESEARCH METHODOLOGY

In order to design the RSVP interface on the small screen devices, a contextual inquiry (Beyer and Holtzblatt, 1998) is used to explore the subjective preference of colors before Experiments 1 and 2 are used.

3.1 Preliminary Preparation－Contextual Inquiry

The contextual inquiry is a structured field interviewing method. It is useful in the early stages of development, since a lot of the information you've got is subjective. We hereinto use it for examining and understanding users and their preferences for colors. According to the result of the contextual inquiry, the subjective preference for colors is used to design the interface of the small display screens on the 17-inches TFT-LCD.

3.1.1 Participants

At the pilot stage of the experiments, twenty undergraduate and graduate students (10 females and 10 males) coming from Tunghai University voluntarily participated the contextual inquiry. Their age distribution ranged from 22 to 30 years old (mean age of 25.55 years old and standard deviation of 1.9 years old). The frequency distribution of background variables for the 20 participants was shown in Table 1. They were surveyed and recorded the subjective preferences of background colors for line graphs and bar charts, and different luminous contrasts with the same foreground luminance. The summary of subjective preferences is going to be developed for the color settings of statistical graphs on the small screen in Experiments 1 and 2.

Table 1. Frequency distribution of participants' background variables in contextual inquiry

Gender		Grade			
Male	Female	Sophomore	Junior	Senior	Graduate
10	**10**	**3**	**1**	**5**	**11**

College			
Engineering	Management	Social Science	Agriculture
1	**16**	**1**	**2**

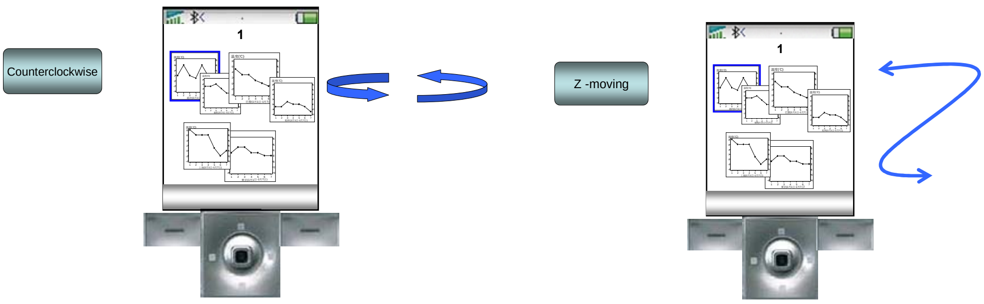
3.1.2 Apparatus and Materials

This study used a Pentium IV desktop computer (CPU1.62GHz, 896MB RAM) with Microsoft's Internet Explore 6.0, a 17-inches TFT-LCD monitor(1280x1024 pixels). The S-PLUS 6.0 was used to plot line and bar graphs of a week's mean daily temperatures. Microsoft Office PowerPoint was used to design the interface of moving direction. Ulead PhotoImpact 10 would be used to illustrate the (R,G,B)/(H,S,B) color combinations.

3.1.3 Construction of Contextual Inquiry

Twenty undergraduate/graduate students participated the contextual inquiry. Firstly, they were asked to choose the most favorite background color based on (R,G,B)/(H,S,B) color combinations of (255,255,255)/(0,0,100), (172,211,115)/(85,46,83), (0,191, 243)/(193, 100,95), and (244, 154,193)/(334,37,96) in Figure 2. Therefore, the corresponding luminous contrasts are 0.89 ((100-11)/100), 0.867 ((83-11)/83), 0.884 ((95-11)/95), 0.885 ((96-11)/96) based on the definition of luminous contrast (Sanders and McCormic, 1992). Secondly, the participants were asked to choose moving direction of collage RSVP in Figure 3(a) which means counterclockwise movement—using the rightward key to move right and the downward key to move down or Figure 3(b) which means Z–shaped movement—using the rightward key only to move right and down.

Figure 2 Background colors of line graphs based on color combinations of (R,G,B) /(H,S,B) from left to right: (255,255,255)/(0,0,100), (172,211,115)/(85,46,83), (0,191, 243)/(193, 100,95), and (244, 154,193)/(334,37,96).



(a) (b)

Figure 3 Moving direction of collage RSVP in which (a) means counterclockwise movement—using the rightward key to move right and the downward key to move down, (b) means Z–shaped movement—using the rightward key to move right and down.

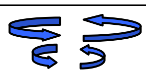
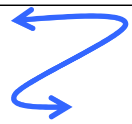
3.1.4 Results of Contextual Inquiry

In the stage of contextual inquiry, we surveyed and collected information not only about subjective preferences of different color hues of background for line graphs and bar charts, but also about color brightness of background. The results of the contextual inquiry is shown in Table 2 and Figure 4 indicated that most subjective preference for background color was the white color ((H, S, B)=(0,0,100) in background matched with (H, S, B)=(160,0,11)) in foreground). Therefore, we adapted luminous contrast 0.89 ((100-11)/100) as the color setting of line graphs and bar charts in the preceding experiments. In addition, the result of Table 3 indicated that the participants chose the moving direction of collage RSVP in terms of Z–shaped movement in Figure 3 (b) most. They also suggested that it's better to combine the two moving directions, that is, the moving direction of collage RSVP can not only move counterclockwise using the rightward/leftward key but also move upward and downward using the upward/downward key. The modified moving direction of collage RSVP is illustrated in Figure 5, and therefore we will adopt it in the following experiments.

Table 2. Results of subjective preference for background color in contextual inquiry

Background				
Hue(H) **Saturation(S)** **Brightness(B)**	**0** **0** **100**	85 46 83	193 100 95	334 37 96
RED(R) **GREEN(G)** **BLUE(B)**	**255** **255** **255**	172 211 115	0 191 243	244 154 193
Luminous contrast	**0.89**	0.867	0.884	0.885
No. of preference	**13**	2	0	5

Table 3. Results of the moving direction in contextual inquiry

moving direction		
No. of preference	**7**	**13**

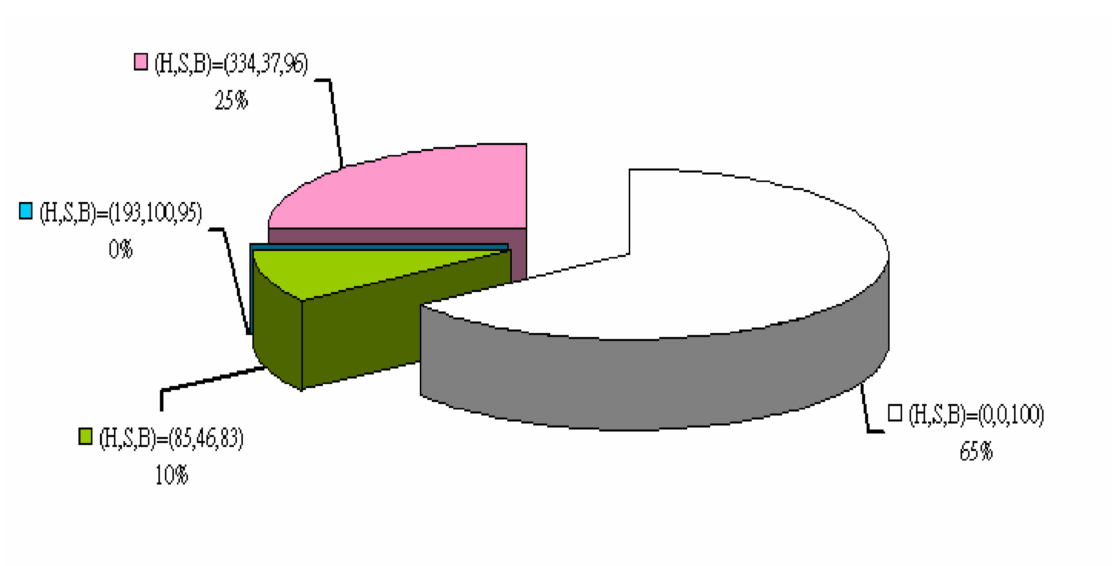


Figure 4 Pie chart of the proportion of subjective preference for four background colors.

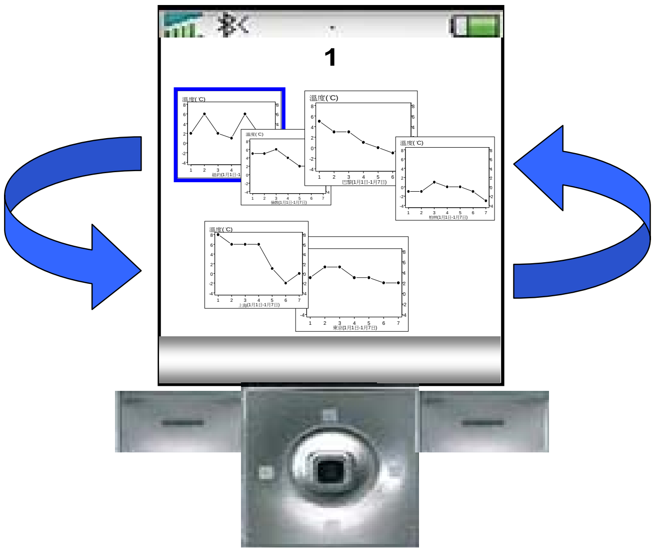


Figure 5 Modified moving direction after the study of contextual inquiry.

3.2 Experiments 1 and 2

Two factorial experiments with blocks were applied to Experiment 1, in which reading the exact value task and identifying the trend task are assigned to twenty-four participants, and Experiment 2, in which comparing two values task and reading the maximum value task are assigned to thirty-six participants. The definition of four tasks were reading the exact value of a single point (Task 1), identifying the trend of a data series (Task 2), comparing two points that belong to the same data series but that have different value on the x axis (Task 3), identifying the highest value for a specific data series (Task 4).

3.2.1 Participants

At the stage of experiments, twenty-four undergraduate and graduate students from Tunghai University voluntarily participated Experiment 1 and thirty-six students participated Experiment 2. The participant pool consisted of twelve females and twelve males (mean age of 23.8 years old, standard deviation of 2.53 years old) in Experiment 1 and eighteen females and eighteen males (mean age of 22.8 years old, standard deviation of 1.76 years old) in Experiment 2. They all had the experience of taking Statistics course and had vision more than 0.8 after vision correction. The frequency distribution of participants' background variables for Experiments 1 and 2 were summarized and shown in Table 4.

3.2.2 Experimental Design

The objective is to evaluate the optimal visualization interface of quantitative data on a small screen. Two factorial designs with blocks are used because individual differences among participants are considered as blocking factor. Three independent factors: (1) RSVP interfaces including four modes of keyhole, carousel, collage, and shelf, plus conventional mode (abbreviated as RSVP), (2) graphical display types including line graph, bar graph, and map (abbreviated as TYPE), and (3) information extraction tasks including reading the exact value, identifying the trend, comparing two values, and reading the maximum value (abbreviated as TASK) are used as the design factors. Response time is defined as the time of completing the assigned task which consists correctly perceiving the target and correctly making the decision. In

Experiments 1 and 2, each participant has to randomly perform 30 trials including 5 RSVP × 3 TYPE × 2 TASK treatment combinations. The order of trials within a block is individually randomized for each participant.

Table 4. Frequency distribution of participants' background variables in Experiment 1 and Experiment 2

Background Variables	**Gender**		**Grade**				
Category	Male	Female	Freshman	Sophomore	Junior	Senior	Graduate
Experiment 1	**12**	**12**	**1**	**4**	**5**	**2**	**12**
Experiment 2	**18**	**18**	**1**	**9**	**12**	**1**	**13**

Background Variables	**College**				
Category	Arts	Science	Engineering	Management	Social Science
Experiment 1	**3**	**2**	**0**	**18**	**1**
Experiment 2	**3**	**2**	**3**	**19**	**3**

3.2.3 Apparatus and Stimuli

The experiment use a Pentium IV desktop computer (256MB RAM) with a 17-inches TFT screen (1280×1024 pixels) and a web camera (Logitech's QuickCam Pro5000) with a built-in microphone. In addition, CyberLink StreamAuthor 3.0 is used to record the process of operation displays. A digital video camera recorder (SONY DCR-PC330) is used to record the overall process of experiments.

In addition, Sony Ericsson T630 mobile phone with the screen height of 3.65 cm and width of 2.85cm is used to illustrate the small screen system. A 17-inches TFT-LCD desktop computer is used to simulate the small screen system. The same visual angle θ is used in both real and simulated system and shown in Figure 6. Its calculation is listed in Equation (1) and Figure 6. Through the pilot study, the distance from eyes to the screen of mobile phone and the distance from eyes to the TFT-LCD screen were measured by fifteen participants. The corresponding mean distances are 23 cm with respect to mobile devices and 80 cm with respect to the simulated screen.

From Equation (1), we know the visual angle. Based on the same visual angle, the screen height of the simulated mobile phone is 12.7 cm (3.65*80/23) to be shown in TFT-LCD screen.

$$\theta_1 = \frac{\theta}{2} = \arctan(a/d) \tag{1}$$

$$\theta_1 = \arctan(\frac{3.65}{2}/23) * \frac{360}{2\pi} = 4.53679^{\circ} \quad \text{That implies that } \theta = 9.07^{\circ}$$

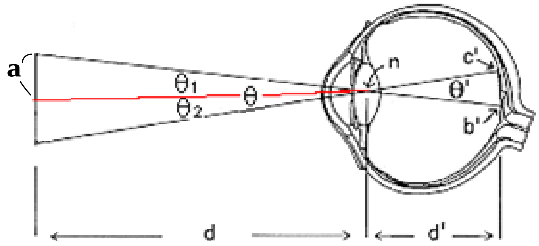


Figure 6 Visual angle and distance.

Based on RSVP modes and graph TYPE, Figures 7-9 indicated the simulated displays applied in Experiments 1 and 2. The contents of questions bank came from the public information announced by Central Weather Bureau of Taiwan (http://www.cwb.gov.tw) and Weather Underground (http://www.wunderground.com). Mean daily temperatures of six cities including New York, London, Paris, Berlin, Shanghai, and Tokyo were cited from the historical data banks. The questions in Experiment 1 are illustrated in Figure A1 of Appendix which is to read the exact value of a data point (e.g., “What is the mean temperature on Jan. 5^{th} in Berlin, German?”) and in Figure A2 of Appendix which is to identify a trend in a series (e.g., “Was the general trend of the mean temperature ascending or descending from Jan. 1^{st} to Jan. 6^{th}?”). The questions in Experiment 2 are illustrated in Figure A3 of Appendix which is to compare two values (e.g., “Which has higher temperature between Jan. 1^{st} and 4^{th}

in London, England?") and are illustrated in Figure A4 of Appendix which is to choose the maximum mean temperature among place A to place C on Jan. 25th, German.

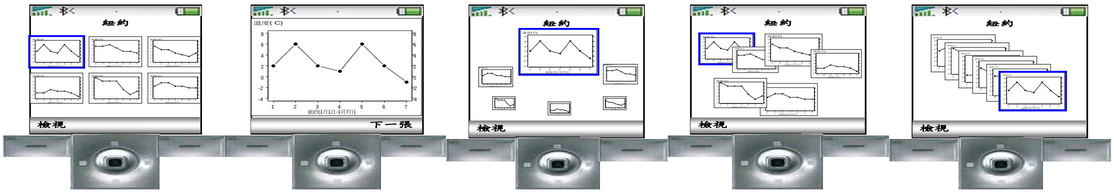


Figure 7 RSVP modes using line graphs from left to right: convention, keyhole, carousel, collage, and shelf.

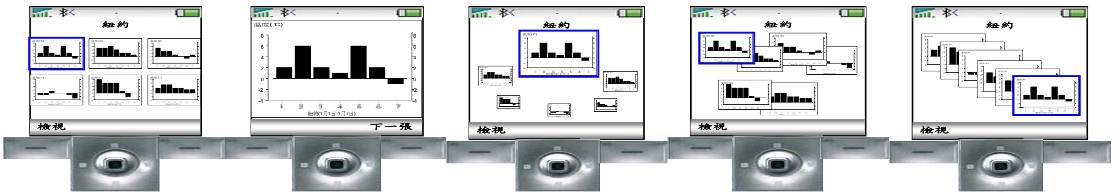


Figure 8 RSVP modes using bar graphs from left to right: convention, keyhole, carousel, collage, and shelf.

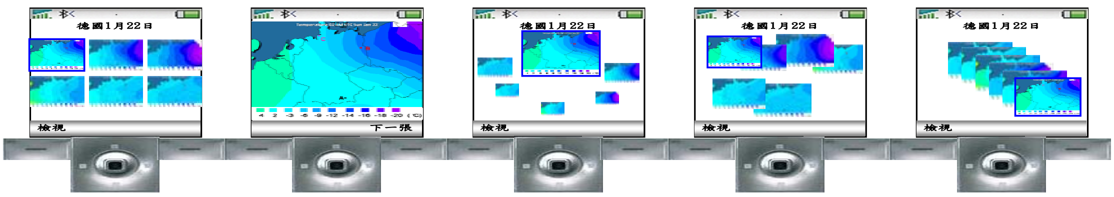
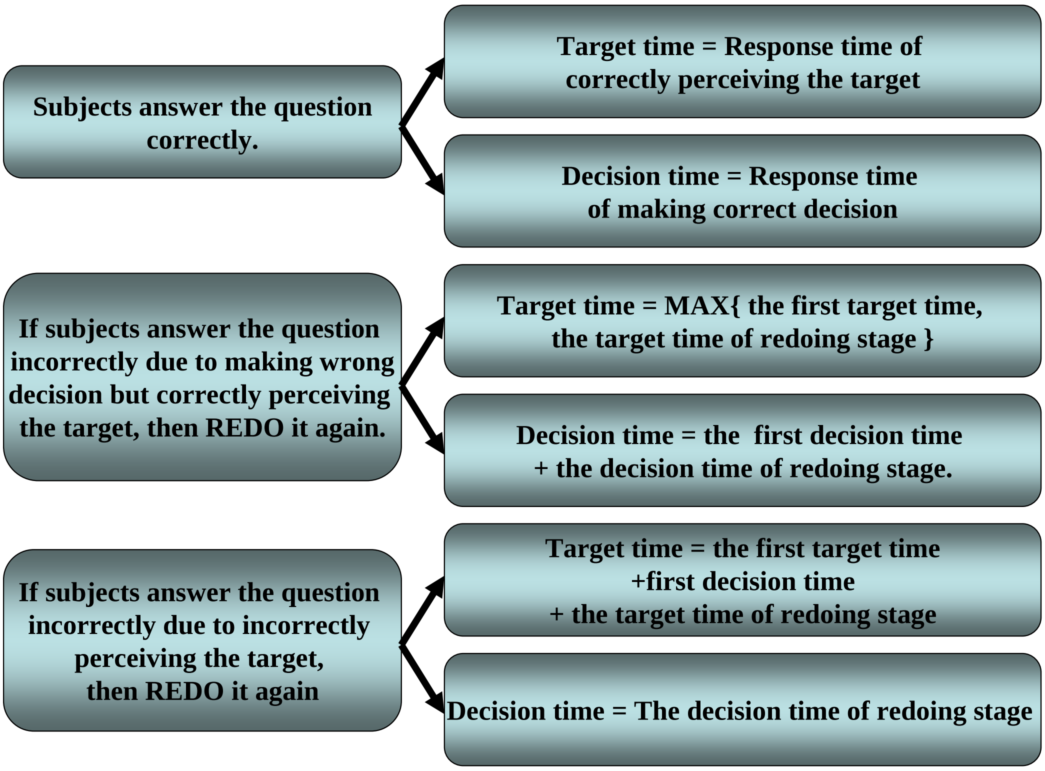


Figure 9 RSVP modes using map graphs from left to right: convention, keyhole, carousel, collage, and shelf.

3.2.4 Experimental Procedure

Participants attended the experiment individually. They sat in front of the TFT at a viewing distance of approximately 50 cm facing a microphone that was connected to a web camera with Stream Author 3.0 being activated. The height of the center of the TFT and the microphone were individually adjusted to the height of the participant. First, instructions were presented on the computer screen that explained the experimental tasks and the displays used. This presentation was self-paced. Both in Experiments 1 and 2, each participant entered a questions' bank at first step. She/he was assigned 30 different information displays depending on the ordering of random assignment of the treatment combinations. When she/he was ready to press the button Q1, the timer started to record the time to finding the target correctly (target time) and the time to making decision correctly (decision time). The sum of target time and decision time is the time to completing the task, called the response time. Then the participant was asked to press Q2 until she/he has completed all the tasks. The computations of target time and decision time are described as follows:



The flow chart of Experiments 1 and 2 was shown in Figure 10. Information gathered from each participant including after-experiment questionnaire (Table 5) and graphical perception tasks with the records of response time.

Table 5. Results of subjective preference for variables in Experiments 1 and 2

Variable	**RSVP**				
Category	Convention	Keyhole	Carousel	Collage	Shelf
Experiment 1	**11**	**3**	**9**	**0**	**1**
Experiment 2	**13**	**7**	**14**	**1**	**1**
Variable	**TYPE**				
Category	Line Graph	Bar Chart	Map		
Experiment 1	**11**	**12**	**1**		
Experiment 2	**16**	**17**	**3**		

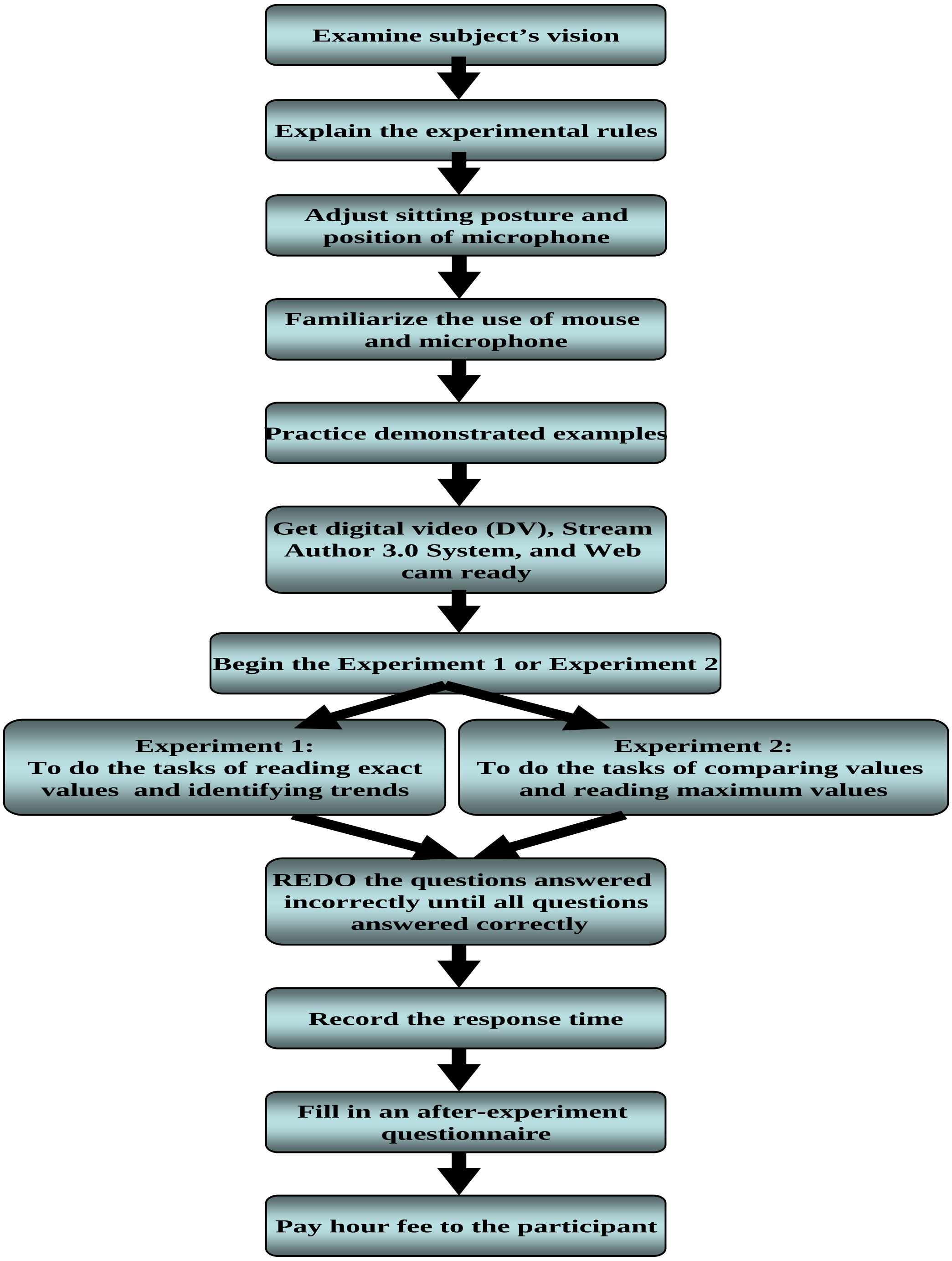


Figure 10 The flow chart of graphical perception experiment.

4. RESULTS AND DISCUSSION

In terms of aids of digital video and webcam, the process of executing the experiment and the voices of answering the questions for each participant will be simultaneously recorded with the aids of Stream Author 3.0. Based on the records, the response time will be computed after experiments.

4.1 Basic Descriptive Statistics

The descriptive statistics of response time for RSVP, TYPE, and TASK are summarized as in Table 6. For RSVP, there are sixty participants and 360 observations. For TYPE, there are sixty participants and 600 observations. For reading the exact value and identifying the trend of TASK, there are twenty-four participants and 360 observations. For comparing two values and reading the maximum value of TASK, there are thirty-six participants and 540 observations. In addition, the descriptive statistics for the response time in Experiment 1 and Experiment 2 are summarized as Table 7. In Experiment 1, twenty-four participants were requested to do task 1 (reading the exact value) and task 2 (identifying the trend). Each combination in the cells of Table 7 has 24 observations. In Experiment 2, thirty-six participants were requested to do task 3 (comparing two values) and task 4 (reading the maximum value). Each combination in the cells of Table 7 has 36 observations. The results in Table 7 indicated that mean response time is different as the information extraction was visualized on the different graphical display types using different RSVP techniques for different tasks.

Table 6. Summary statistics of response time for RSVP, TYPE, and TASK

RSVP	**Obs.**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
carousel	360	10.730	4.21	3.067	37.348
collage	360	11.670	4.85	3.376	43.201
convention	360	11.029	4.37	3.364	34.719
keyhole	360	11.619	5.76	3.835	55.211
shelf	360	11.293	4.99	5.031	46.598
TYPE	**Obs.**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
bar	600	10.548	3.83	3.067	31.217
line	600	10.873	4.21	3.141	43.201
map	600	12.383	6.08	3.376	55.211
TASK	**Obs.**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
EXACT	360	13.015	6.93	3.067	55.211
TREND	360	11.534	4.40	4.546	38.721
COMPARISON	540	11.207	4.15	3.376	43.201
MAXIMUM	540	9.987	3.66	3.141	29.879

Table 7. Summary statistics of response time for four tasks in Experiment 1 and Experiment 2

	Experiment 1				**Experiment 2**			
TASK	**Exact value**		**Trend**		**Comparison**		**Maximum value**	
RSVP/TYPE	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
carousel/bar	9.459	2.859	10.896	3.455	10.422	3.322	9.086	3.22
carousel/line	9.89	2.776	10.59	4.345	12.18	4.509	8.913	2.786
carousel/map	15.941	7.92	10.885	3.538	11.025	3.686	10.571	3.131
collage/bar	10.41	3.088	12.228	4.808	11.761	3.751	9.892	4.201
collage/line	12.748	4.98	11.26	5.016	**14.005**	**6.769**	10.439	3.307
collage/map	16.122	6.215	12.718	4.507	9.732	3.648	10.55	3.836
convention/bar	9.671	4.275	11.981	2.976	11.218	3.344	9.856	3.5
convention/line	9.941	3.693	10.925	3.086	11.751	4.517	10.1	3.933
convention/map	16.684	7.498	10.853	3.859	10.579	3.091	10.085	4.305
keyhole/bar	10.885	4.421	10.425	4.178	11.161	4.945	9.027	3.45
keyhole/line	10.493	3.714	10.888	3.991	10	3.229	9.761	3.5
keyhole/map	**21.706**	**11.057**	**14.288**	**6.236**	11.698	4.144	**12.083**	**4.796**
shelf/bar	11.527	5.088	11.297	3.59	11.361	3.778	9.505	2.563
shelf/line	12.324	5.492	11.003	2.749	10.35	2.964	10.342	4.004
shelf/map	17.421	9.979	12.78	6.935	10.868	3.971	9.601	3.147

4.2 Proposed Models

The statistical models of Experiments 1 and 2 were proposed as following:

$$Y_{ijkl} = \mu + \tau_i + \alpha_j + \beta_k + \gamma_l + (\alpha\beta)_{jk} + (\alpha\gamma)_{jl} + (\beta\gamma)_{kl} + (\alpha\beta\gamma)_{jkl} + \varepsilon_{ijkl}, \quad (2)$$

where τ_i is the effects of blocks (between subjects), α_j is the effects of TASK, β_k is the effects of RSVP, γ_l is the effects of TYPE, $(\alpha\beta)_{jk}$ is the interaction effects of TASK and RSVP, $(\alpha\gamma)_{jl}$ is the interaction effects of TASK and TYPE, $(\beta\gamma)_{kl}$ is the interaction effects of RSVP and TYPE, $(\alpha\beta\gamma)_{jkl}$ is the interaction effects of TASK, RSVP, and TYPE, and ε_{ijkl} is the error terms. The basic assumptions of ANOVA model are that the error terms distributed independently and identically as normal with mean 0 and constant variance σ^2. Unfortunately, from ANOVA residual analysis, the patterns between residuals and the fitted values are apparent (see Figures 11 and 12). It means that the variances of error terms ε_{ijkl} are not constant.

The possible remedy is to use Box-Cox procedure to stabilize the error variances from the family of power transformation. The family of power transformations is of the form:

$$\mathrm{Y}' = Y^{\lambda} \quad (3)$$

where λ is a parameter to be determined from the data. For each λ value, the Y_i^{λ} observations are first standardized so that the magnitude of the error sum of squares does not depend on the value of λ:

$$W_i = \begin{cases} \dfrac{(Y_i^{\lambda} - 1)}{\lambda \dot{Y}^{\lambda-1}} & \lambda \neq 0 \\ \dot{Y} \ln Y_i & \lambda = 0 \end{cases} , \quad (4)$$

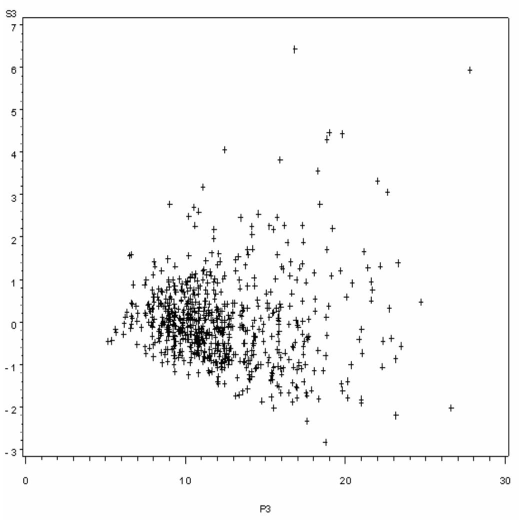
where $\dot{Y}$ denotes the geometric mean of the Y_i observations.

Figure 13 contains the S-PLUS Box-Cox results for Experiment 1. It consists of a plot of sum squares of error (*SSE*) as a function of λ. From the plot, it is clear that a power value near λ =-0.2 is indicated because the minimum sum squares of error is 9350. However, the choice of λ =0 is easier to interpret since it is corresponding to the logarithmic transformation than λ =-0.2. Similarly, Figure 14 contains the SPLUS Box-Cox results for Experiment 2. From the plot, it is clear that a power value near λ =-0.06 is indicated because the minimum sum squares of error is 9512. Similarly, λ =0 is reasonable according to the Box-Cox approach.

After Box-Cox transformation, both the statistical models for Experiments 1 and 2 are modified as Equation (5).

$$\boldsymbol{Y_{ijkl}^{(\lambda)} = \mu + \tau_i + \alpha_j + \beta_k + \gamma_l + (\alpha\beta)_{jk} + (\alpha\gamma)_{jl} + (\beta\gamma)_{kl} + (\alpha\beta\gamma)_{jkl} + \varepsilon_{ijkl}} , \quad (5)$$

Based on Equation (5), the studentized residuals plots for Experiments 1 and 2 are displayed in Figures 15 and 16. They look like no more patterns between studentized residuals and fitted values. Using the Box-Cox transformation is good enough to eliminate the pattern of residual plots. Furthermore, the normal probability plots of studentized residuals (Figures 17 and 18) and the corresponded Kolmogorov-Smirnov normality tests indicate that all the residuals based on Equation (5) are distributed as normal distributions. From the residual analysis, the use of natural logarithmic transformation of response time for Experiments 1 and 2 is appropriate.



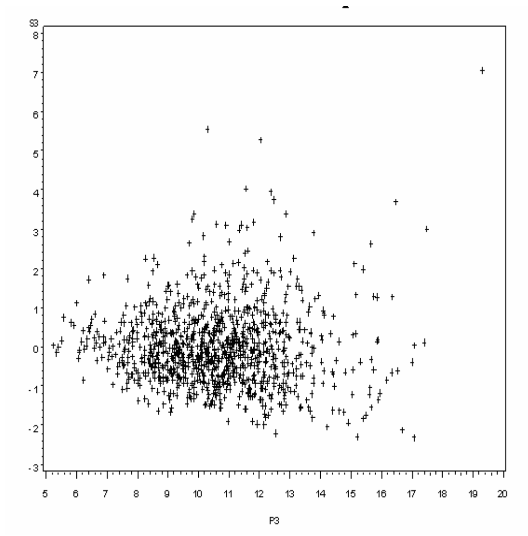
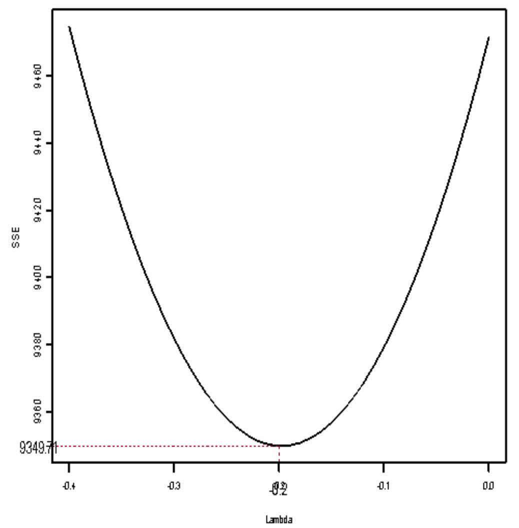


Figure 11 Scatter plot of studentized residuals versus fitted values for Experiment 1.

Figure 12 Scatter plot of studentized residuals versus fitted values for Experiment 2.



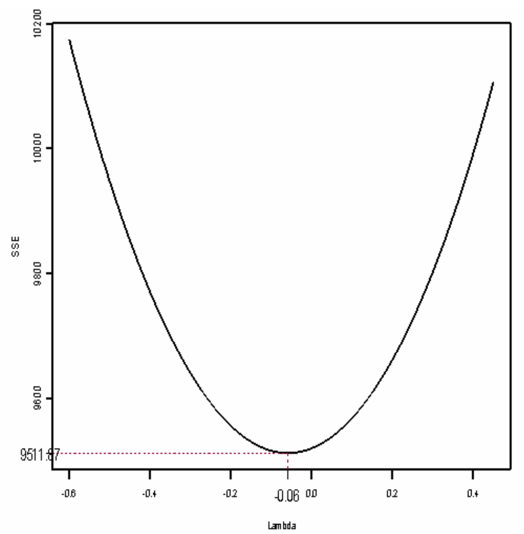
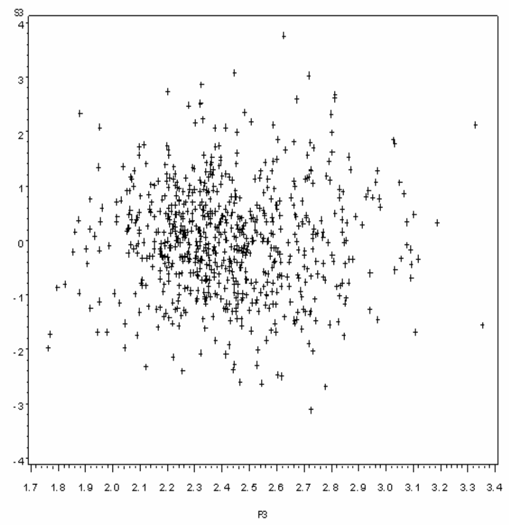


Figure 13 Box-Cox transformation results for Experiment 1.

Figure 14 Box-Cox transformation results for Experiment 2.



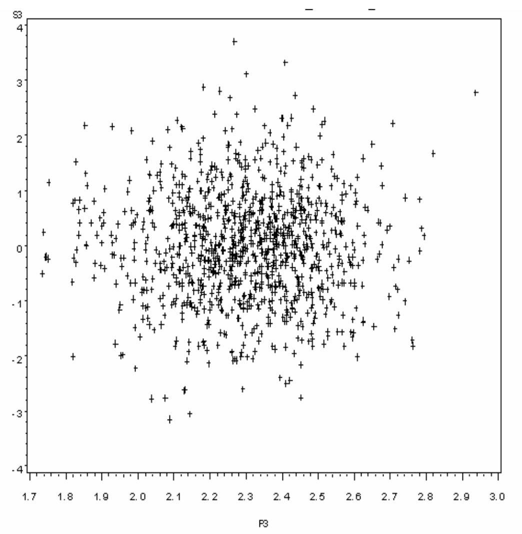
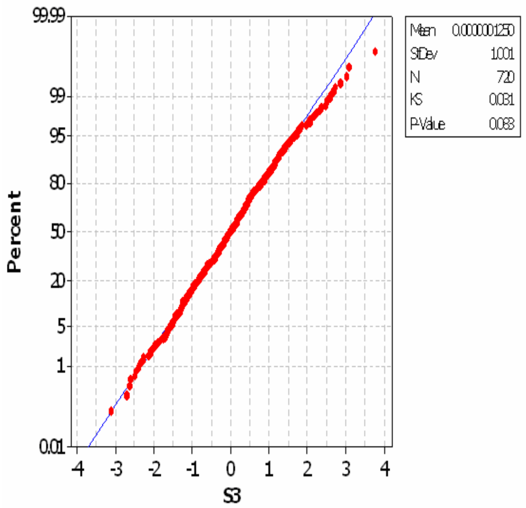


Figure 15 Scatter plot of studentized residuals versus fitted values for Experiment 1.

Figure 16 Scatter plot of studentized residuals versus fitted values for Experiment 2.



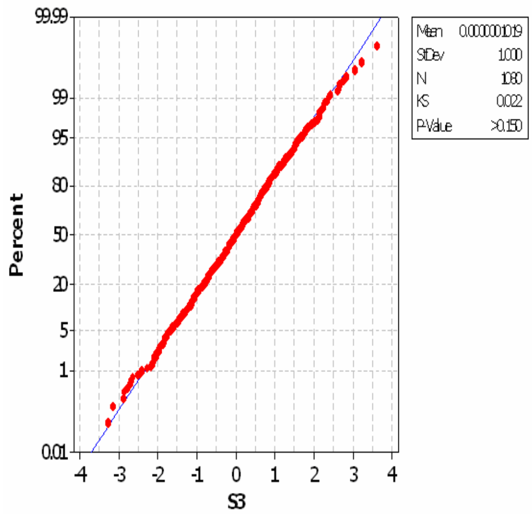


Figure 17 Normal probability plot of studentized residuals for Experiment 1.

Figure 18 Normal probability plot of studentized residuals for Experiment 2.

4.3 Results of Analysis of Variance

The results of ANOVA of log response time for Experiments 1 and 2 are shown in Table 8. The fitting models for Experiments 1 and 2 are the same and shown in Equation (6).

$$\log Y_{ijkl} = \mu + \tau_i + \alpha_j + \beta_k + \gamma_l + (\alpha\gamma)_{jl} + (\beta\gamma)_{kl} + \varepsilon_{ijkl}\,, \qquad (6)$$

Table 8. *F* Values of three-way ANOVA with blocks for log response time

	Experiment 1				Experiment 2			
Source of variation	*DF*	*Sum of Squares*	*F* Value	*P* Value	*DF*	*Sum of Squares*	*F* Value	*P* Value
Block	23	23.42	9.04	**<.0001***	35	29.024	8.75	**<.0001***
RSVP	4	1.61	3.56	**0.0069***	4	0.367	0.97	0.4239
TYPE	2	11.1	49.25	**<.0001***	2	0.284	1.50	0.2237
RSVP* TYPE	8	1.82	2.02	**0.0422***	8	2.807	3.70	**0.0003***
TASK	1	0.83	7.40	**0.0067***	1	3.661	38.64	**<.0001***
RSVP* TASK	4	0.4	0.90	0.4663	4	0.216	0.57	0.6850
TYPE* TASK	2	5.81	25.79	**<.0001***	2	1.107	5.84	**0.0030***
RSVP*TYPE*TASK	8	1.02	1.13	0.3413	8	1.437	1.90	0.0571
Error	667	75.16			1015	96.15		
Corrected Total	719	121.17			1079	135.06		

Note: “*” denotes statistical significance at α =0.05.

In this analysis, differences between cells’ means include the interaction effects between RSVP and TYPE and between TYPE and TASK as well as their main effects. However, the three-factor interaction of RSVP*TYPE*TASK is not statistically significant. For the subsequent post hoc pair-wise comparisons of RSVP and TYPE in Experiment 1, the results of Duncan multiple range test of log response time are shown in Table 9 which compare all 5×3 cell means pair-wisely to determine which pairs differ significantly. This analysis indicates that at the TYPE level bar and line charts the mean response time is almost the same for all RSVP modes, however, the mean response time for TYPE level map is significantly longer than both types bar and line chats (Figures 19 and 20). For the type of map, the keyhole RSVP design is specially worse than the other RSVP designs for both tasks of reading the exact value and identifying the trend. In general, line and bar charts are significantly better than map for any kind of RSVP designs whatever tasks are assigned.

Table 9. Results of Duncan's multiple range tests of RSVP and TYPE for Experiment 1

Duncan Grouping		log Mean	N	RSVP/TYPE
	A[1]	2.769	48	keyhole/map
	B	2.592	48	collage/map
	B	2.586	48	shelf/map
C	B	2.520	48	convention/map
C	B	2.500	48	carousel/map
C	D	2.408	48	collage/line
C	D	2.403	48	shelf/line
C	D	2.377	48	shelf/bar
C	D	2.369	48	collage/bar
	D	2.324	48	convention/bar
	D	2.306	48	keyhole/line
	D	2.292	48	keyhole/bar
	D	2.289	48	convention/line
	D	2.274	48	carousel/line
	D	2.263	48	carousel/bar

Note 1: Log means with the same letter denote no significant difference.

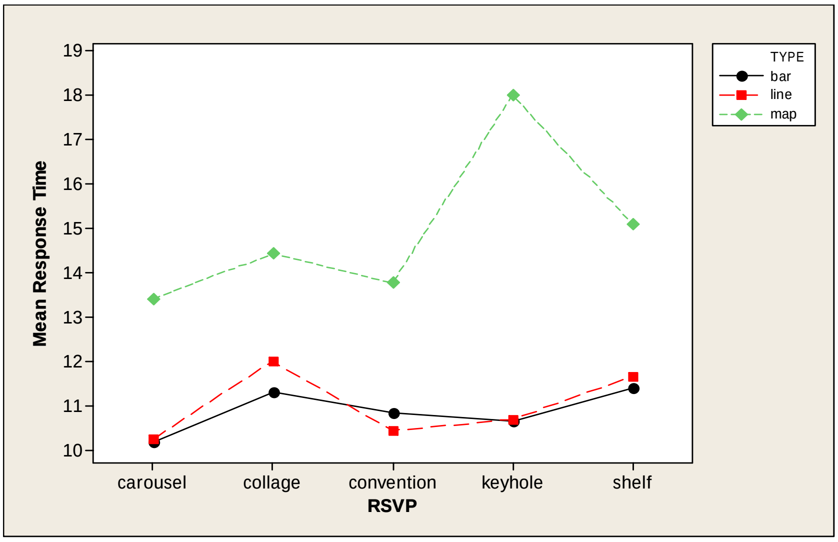


Figure 19 Interaction plot of response time of RSVP and TYPE for Experiment 1.

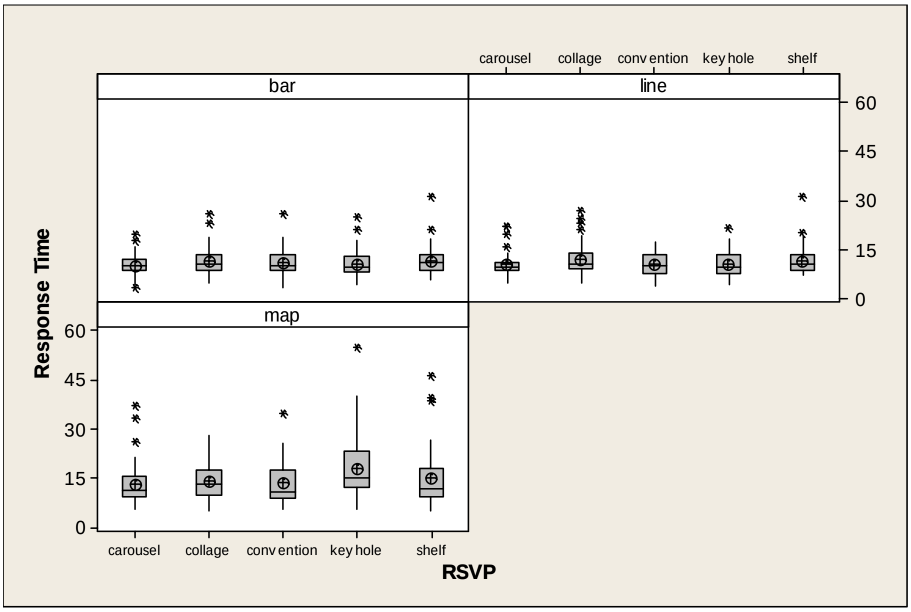


Figure 20 Box plots of response time of RSVP at the levels of TYPE for Experiment 1.

As mentioned previously, Table 8 also shows that significant differences between the interaction of TYPE and TASK for Experiments 1 and 2. For the subsequent post hoc pair-wise comparisons of TYPE and TASK in Experiment 1, the results of Duncan multiple range test of log response time are shown in Table 10 which compare all 3×2 cell means pair-wisely to determine which pairs differ significantly. This analysis indicates that at the TASK level 1 (reading the exact value), the mean response time is the same for TYPE bar and line, and that the mean response time for TYPE map is significantly longer than both types bar and line chats (Figures 21 and 22). Similarly, at the TASK level 2 (identifying the trend), the mean response time is the same for TYPE bar and line, and that the mean response time for TYPE map is also significantly longer than both types bar and line chats (Figures 21 and 22). In general, line and bar charts are significantly better than map for both tasks of reading the exact value and identifying the trend. Besides, the map-trend design is better than the map-exact ones.

Table 10. Results of Duncan's multiple range tests of TYPE and TASK for Experiment 1

Duncan Grouping		log Mean	N	TYPE/TASK
	A[3]	2.751	120	map/EXACT
	B	2.436	120	map/TREND
C	B	2.378	120	bar/TREND
C	D	2.339	120	line/TREND
C	D	2.333	120	line/EXACT
	D	2.272	120	bar/EXACT

Note 3: Log means with the same letter denote no significant difference.

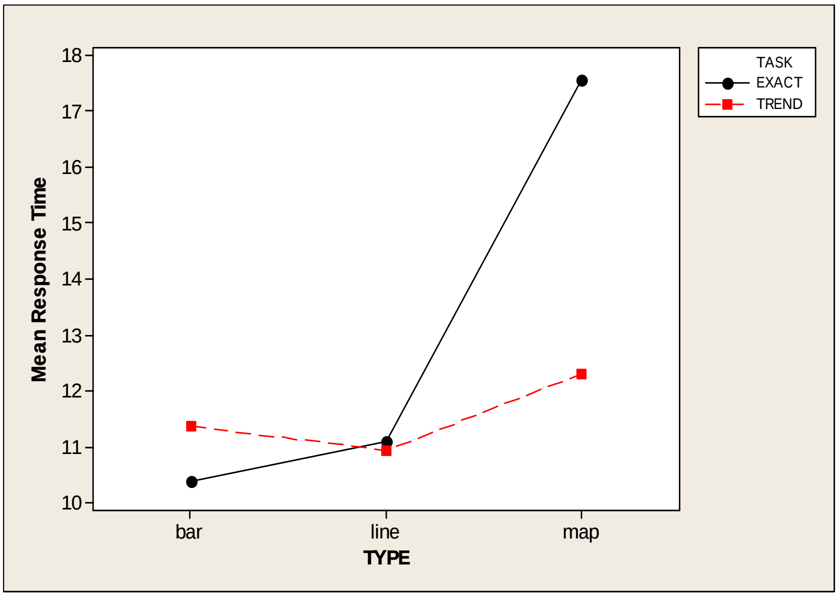


Figure 21 Interaction plot of response time of TYPE and TASK for Experiment 1.

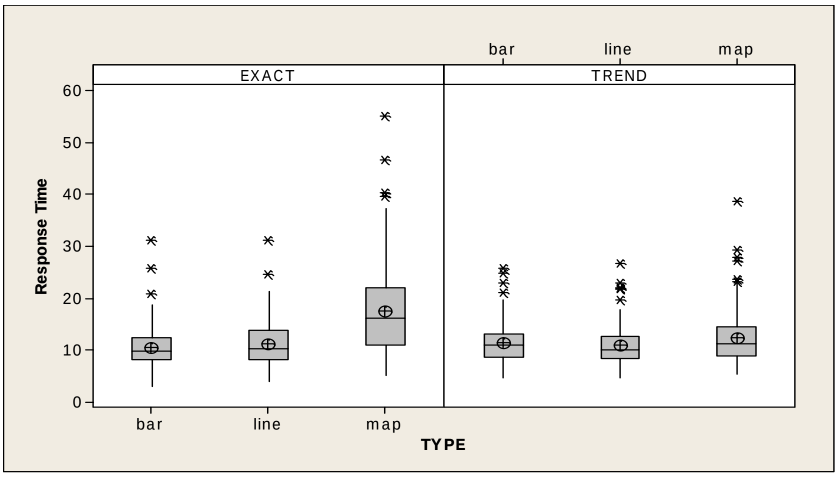


Figure 22 Box plots of response time of TYPE at the levels of TASK for Experiment 1.

Similarly, for the subsequent post hoc pair-wise comparisons of RSVP and TYPE in Experiment 2, the results of Duncan multiple range test of log response time are shown in Table 11 which compare all 5×3 cell means pair-wisely to determine which pairs differ significantly. This analysis indicates that at the TYPE level bar, line, and map the mean response time are almost the same for both convention and shelf RSVP modes, however, the mean response time for TYPE level map is significantly longer than both types bar and line chats for keyhole RSVP mode but shorter than both types bar and line chart for collage RSVP mode (Figures 23 and 24). In addition, the mean response times for TYPE level bar, line, and map are not significantly different for carousel RSVP mode. For the type of line chart, the collage RSVP design is specially worse than the other RSVP designs. In general, the carousel-bar, keyhole-bar, and keyhole-line designs are better than other combinations of RSVP*TYPE for Experiment 2.

Table 11. Results of Duncan's multiple range tests of RSVP and TYPE for Experiment 2

Duncan Grouping			log Mean	N	RSVP/TYPE
	A[2]		2.425	72	collage/line
B	A		2.406	72	keyhole/map
B	A	C	2.331	72	carousel/map
B	A	C	2.322	72	collage/bar
B	A	C	2.315	72	convention/line
B		C	2.301	72	convention/bar
B		C	2.300	72	shelf/bar
B		C	2.288	72	carousel/line
B		C	2.285	72	shelf/line
		C	2.283	72	convention/map
		C	2.272	72	shelf/map
		C	2.250	72	collage/map
		C	2.235	72	keyhole/line
		C	2.229	72	keyhole/bar
		C	2.221	72	carousel/bar

Note 2: Log means with the same letter denote no significant difference.

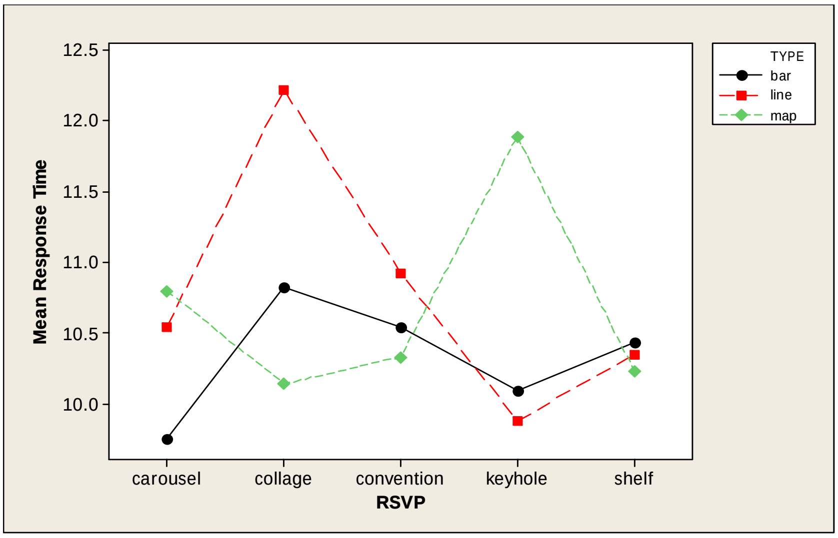


Figure 23 Interaction plot of response time of RSVP and TYPE for Experiment 2.

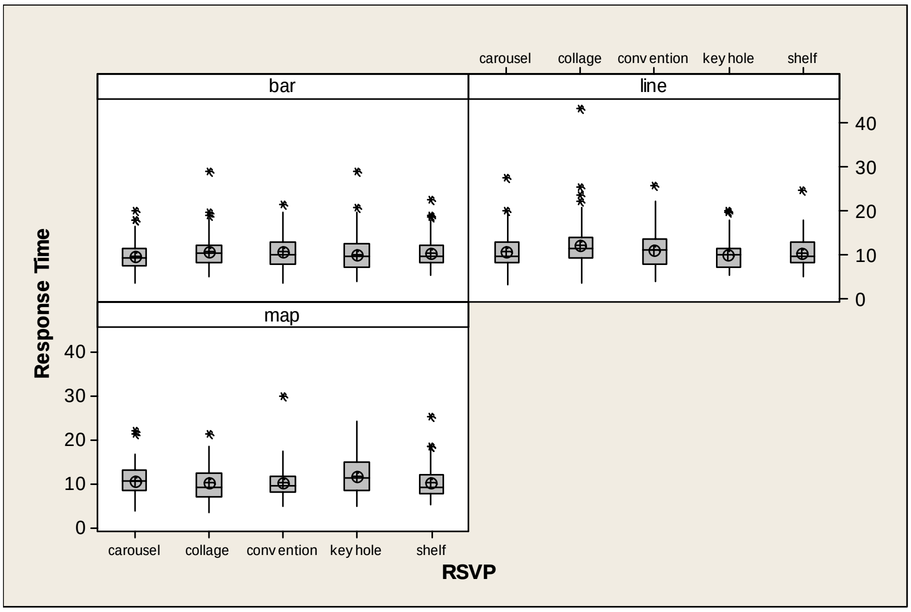


Figure 24 Box plots of response time of RSVP at the levels of TYPE for Experiment 2.

In addition, for the post hoc pair-wise comparisons of TYPE and TASK in Experiment 2, the results of Duncan multiple range test of log response time are shown in Table 12. This analysis indicates that at the TASK level 4 (reading the maximum value), the mean response time is consistently shorter than ones at the TASK level 3 (comparing two values) for bar and line types. For the mean response time of TYPE map is longer than both types bar and line chats at the TASK level of reading the maximum value (Figures 25 and 26) but conversely, the mean response time of TYPE map is shorter than both types bar and line chats at the TASK level of comparing two values.

Table 12. Results of Duncan's multiple range tests of TYPE and TASK for Experiment 2

Duncan Grouping		log Mean	N	TYPE/TASK
	A[4]	2.386	180	line/XCOMPARISON
B	A	2.360	180	bar/XCOMPARISON
B	A	2.322	180	map/XCOMPARISON
B	C	2.295	180	map/MAXIMUM
D	C	2.233	180	line/MAXIMUM
D		2.190	180	bar/MAXIMUM

Note 4: Log means with the same letter denote no significant difference.

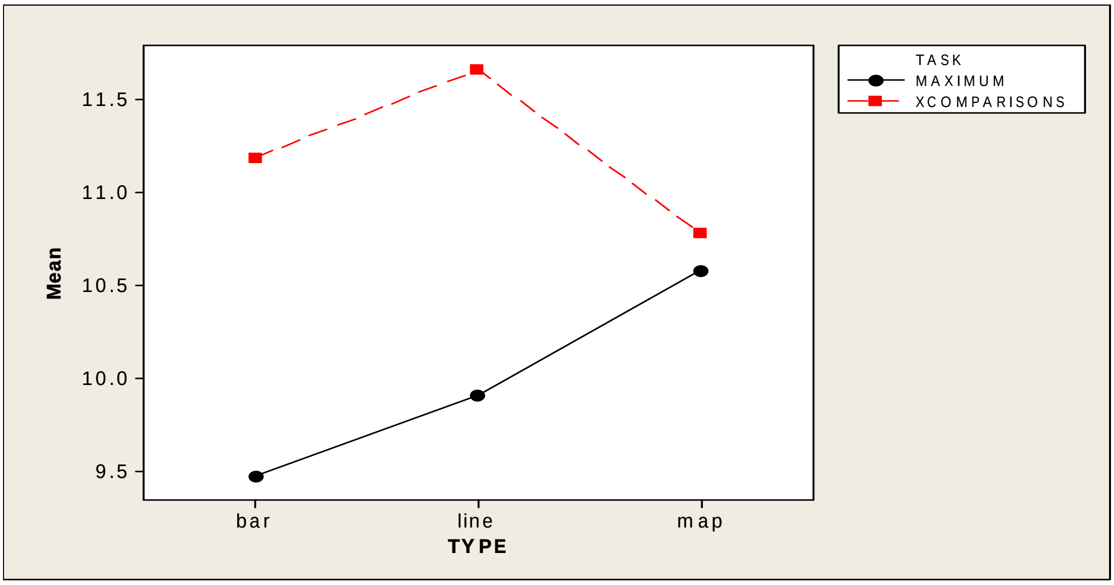


Figure 25 Interaction plot of response time of TYPE and TASK for Experiment 2.

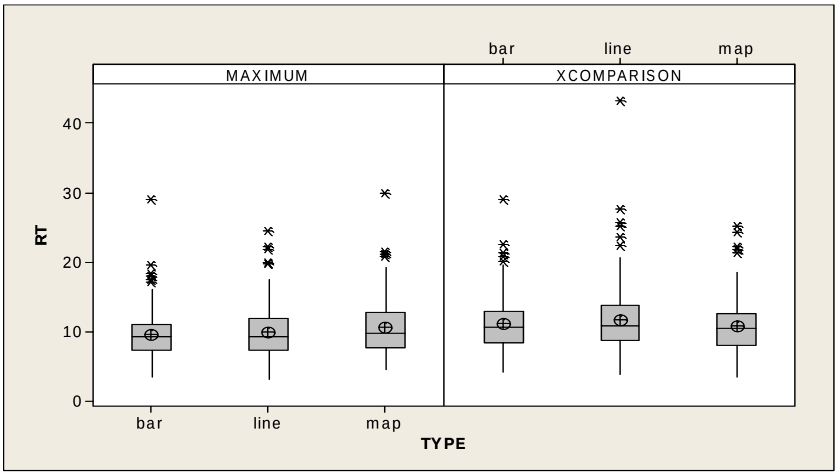


Figure 26 Box plots of response time of TYPE at the levels of TASK for Experiment 2.

4.4 Discussions

The results of Experiments 1 and 2 show that the effect of RSVP modes is statistically significant on small screen devices. It is similar to the result from De Bruijn et al. (2002), "RSVP browsing functionality appears to be vindicated also by the fact that this is exactly the functionality implemented in other browsers designed for Web browsing on small screen devices." In addition, it is consistent with the results of De Bruijn and Spence (2002) that the keyhole RSVP does not have good design presentation since several new images are presented in turn and the image would have been no longer visible in the keyhole mode.

In Experiment 1, for the task of identifying the trend, the line-type is significantly better than others. This result reached the same conclusion with Meyer et al. (1997). They claimed that trends can easily be read from line graphs because the slope of a line is equivalent to its trend and can be directly perceived.

For graphical perception, map-type is significantly worse than others. One possible reason is that a statistical map was encoded by different color hues and one has to decode their real values by using color hues. An elementary perceptual task of judging color hue has to be performed which falls in the bottom of perceptual hierarchy (Cleveland and McGill, 1984).

5. CONCLUDING REMARK

5.1 Conclusion

The results of Experiment 1 and Experiment 2 have showed that both the interaction of RSVP and TYPE as well as the interaction of TASK and TYPE are statistically significant. For the tasks of reading the exact value and identifying the trend, line and bar charts are significantly better than map for any kind of RSVP designs. For the task of comparing two values, the collage-map, shelf-map, convention-map, carousel-bar, and keyhole-bar designs have relatively smaller mean response times. It should not be recommended for collage-line design for comparing two values. For the task of reading the maximum, carousel-bar, keyhole-bar, and keyhole-line designs are worthy to be recommended, but keyhole-map design is not recommended for the small screens.

5.2 Limitations of Experiment

A TFT-LCD desktop computer is used to simulate the small screen system. There are six images shown on the small screen. In order to balance out the case of the images easier to recognize than others, the target image is randomization and equalization, so that none of RSVP modes are biased due to their target images. The participants use the moving keys to choose the target image and control the pace by themselves.

5.3 Further Research

The effect of 3D in RSVP modes is that the images displayed using a 3D approach. This could have been a factor in its increased performance. Further work is required to investigate the effect of 3D metaphors in RSVP modes. Furthermore, the touch screen design interface is more popular since Apple’s iPhone and LG’s PRADA PHONE are presented to the public. Limitation to the use of moving keys in our study, the usability of touch screen is worthy of our continued investigation. Moreover, the images sizes and the task complexities are also worth a further study for the graphical perception on small screens.

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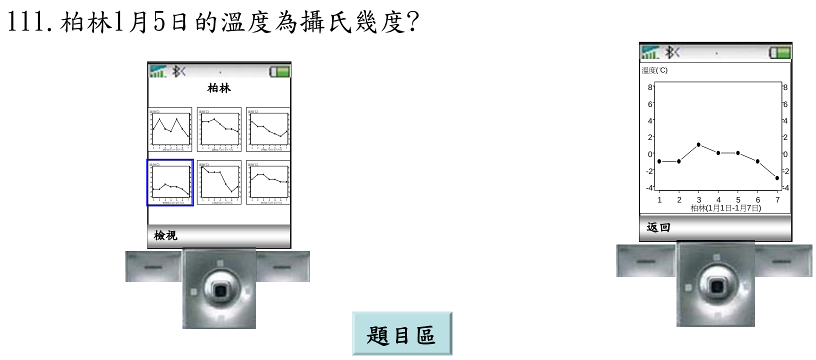
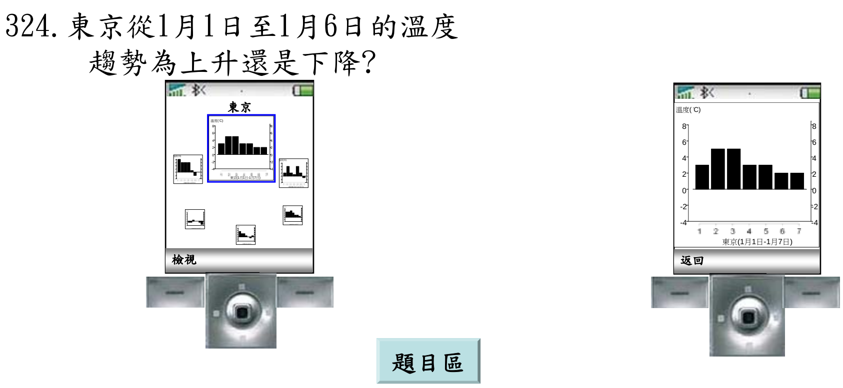
APPENDIX

The following figures are the illustration of the question bank for the four tasks: reading the exact value, identifying the trend, comparing two values, and reading the maximum value.



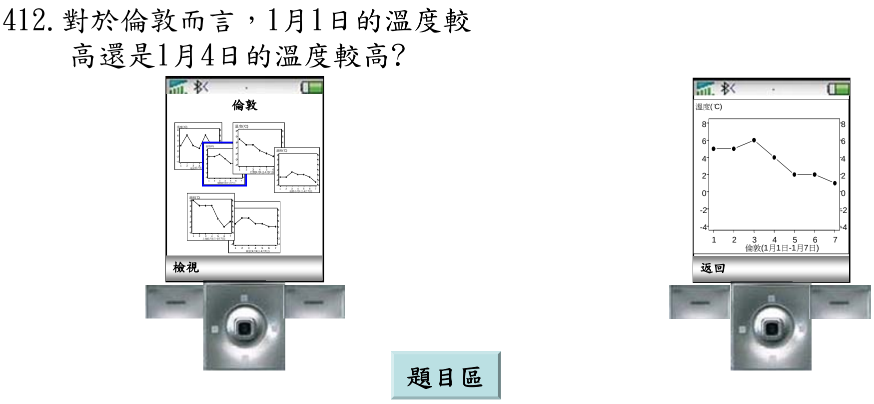
(a) (b)

Figure A1 Illustration of the question for reading an exact value in terms of convention mode and line type**:** (a) showing the mean temperatures, (b) linking to the targeted city.



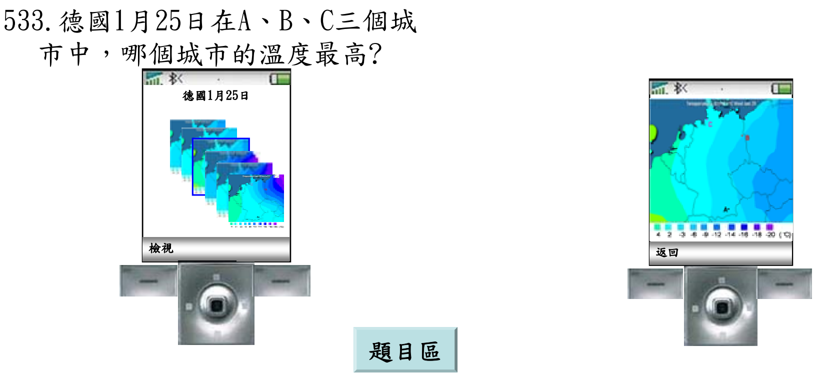
(a) (b)

Figure A2 Illustration of the question for identifying a trend in terms of carousel mode and bar type**:** (a) showing the mean temperatures, (b) linking to the targeted city.



(a) (b)

Figure A3 Illustration of the question for comparing two values in terms of collage mode and line type**:** (a) showing the mean temperatures, (b) linking to the targeted city.



(a) (b)

Figure A4 Illustration of the question for reading maximum in terms of shelf mode and map type**:** (a) showing the mean temperatures, (b) linking to the targeted date.