The Use of Dynamic Display to Improve Reading Comprehension for the Small Screen of a Wrist Watch

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Abstract. This study explored the feasibility of displaying dynamic Chinese text on the screen of a wrist watch. Three design factors (i.e., dynamic display, presentation method, and speed) were examined to investigate their effects on users' reading comprehension under two different conditions of task types. The results of this study indicated the following: (1) There was no significant difference between leading display and RSVP in both single- and dual-task conditions; (2) Presentation method was a significant factor. The participant's reading comprehension was significantly better with the word-by-word format than with the character-by-character one in both single- and dual-task conditions; (3) The participant's reading comprehension was not significantly different among the three different speed settings in the single-task condition. However, participants had significantly higher reading comprehension scores under the slower speed settings of 150 and 250 cpm than under the faster speed setting of 350 cpm in the dual-task condition.

Keywords: Dynamic display, Leading display, Rapid serial visual presentation, Reading comprehension, Small screen, Wrist watch.

1 Introduction

In 2002, Microsoft Chairman Bill Gates introduced the Smart Personal Objects Technology (SPOT) Initiative, aimed at improving the function of everyday objects through the injection of software. SPOT wrist watches are the first SPOT-based application. SPOT turns wrist watches into mobile tools ripe to receive information services and advertisings via radio-frequency links. Recently, users can receive timely information (e.g., traffic information, urgent message, and news) by wrist watches instead of other mobile electronic devices. Fig. 1 shows a snapshot of SPOT wrist watches. Although SPOT wrist watches offer the convenience of portable user interfaces, the display space of wrist watches, however, is at a premium. The amount of information that can be displayed on the screen of wrist watches at one time is very limited. One possibility is to adopt automatic dynamic displays, in that onscreen text moves, to overcome the limitations caused by a small screen [1], [2], [3], [6], [8], [10], [11], [13].

Past studies related to dynamic display were mainly for the reading of English text. However, there are great differences between the reading of dynamically presented Chinese and English. Therefore, further studies are needed.

M.J. Smith, G. Salvendy (Eds.): Human Interface, Part I, HCII 2007, LNCS 4557, pp. 814–823, 2007.

Fig. 1. A snapshot of SPOT wrist watches

1.1 Dynamic Display

The types of dynamic displays widely used in various media include leading display and rapid serial visual presentation (RSVP). In a leading display, text scrolls horizontally from right to left on a one-line display [3], [6], [7], [8], [13]. Leading displays can be divided into the "leaping" or the "smooth-sliding" types. A leaping type of leading display takes the form of the words leaping a specific distance. In contrast, a smooth-sliding type of leading display takes the form of words sliding smoothly by in a pixel-by-pixel manner. Another kind of dynamic display is RSVP, by means of which words are displayed successively, quickly, and continuously in a fixed area of the screen so that users can read words without moving their eyes [1], [2], [3], [6], [7], [8], [10], [11].

The leading display and RSVP have been compared with static display in terms of their effects on the reading of English. As was pointed out in the research, compared with the leading display, the static display had a greater reading efficiency [3]. On the other hand, the comparison between RSVP and static display was believed to have resulted in no significant differences [2], [6].

Meanwhile, studies have also compared directly the different influences of leading display and RSVP on reading English text. A study showed that a higher reading accuracy in RSVP than in the leaping type of leading display [6]. However, another study compared the influences of a smooth-sliding leading display and RSVP on reading comprehension, the result of their study showed that there were no significant differences between the RSVP and the smooth-sliding type of leading display [7].

In addition, there are some studies concerning the dynamic display of Chinese. A study explored the influences of three dynamic displays (i.e., scrolling, leading, and RSVP) on reading comprehension when Chinese characters were presented on different forms of small-screen interfaces. The results revealed that, when a laptop and a mobile phone were involved, users showed no significant differences on comprehension while reading written messages respectively under the conditions of smooth-sliding leading display and RSVP [2]. Another study compared the reading comprehension in the conditions of smooth-sliding leading display and RSVP; the results revealed that the participants had greater recall accuracy with the smooth-sliding leading display than with RSVP [8].

1.2 Presentation Method

Studies compared the presentation method of word-by-word format, sentence-by-sentence format, and the static display. The results showed that no significant differences existed among the effects of the three methods on the reading efficiency [10]. A study also compared another three presentation methods, including word-by-word, three-line, and ten-line formats. The results showed that the participants in RSVP revealed significantly better reading comprehension under the conditions of word-by-word and ten-line formats [1]. The above studies were conducted on the basis of English texts, but the differences between English and Chinese have made it necessary that the exploration of presentation methods for Chinese should be carried out in accordance with Chinese characteristics. Although character in Chinese is the smallest reading unit, it has been pointed out in studies that while reading Chinese characters the eyes usually stare at several characters at the same time. The word is often an important unit in reading Chinese text [4]. The Chinese word consists of one or several Chinese characters with no salient boundary between the words. Research pointed out that reading accuracy would not be affected by any salient boundaries resulting from the insertion of spaces between Chinese words but that the reading time will be shortened [4]. That is to say, spaces between words may help readers separate Chinese characters into words and thus lower the cognitive load and increase their reading speed. Lin and Shieh [8] have investigated the effects of the presentation method with character-by-character and word-by-word formats. It was found that, for the leading display on a single-line screen, the effects on the participants' recall efficiency showed that the word-by-word format scored greater results than did the character-by-character format. The study also investigated the situation with RSVP, and tried to discover the effects of these two presentation methods, i.e., the single-line eight-character format and the word-by-word format. The results of the study revealed that the word-by-word format is significantly superior to the single-line eight-character format.

1.3 Speed

The display speed for the reading of English text is calculated with word as a unit, that is, words per minute, or wpm. An investigation was conducted to reveal the relationships between RSVP and the three display speeds (250, 450 and 650 wpm). Significant differences were found among the different display speeds, with the display speed of 250 wpm producing the best reading comprehension [1]. Juola et al. [6] study the effects of the leading display and RSVP in the reading of English text. The results showed that when the dynamic display was in the manner of leading, participants had the highest reading accuracy when the display speed was 260 wpm; when the dynamic display was in the manner of RSVP, no significant differences were observed for the display speeds of 260 and 171 wpm.

The display speed for the reading of Chinese text is calculated with character as a unit, that is, characters per minute, cpm. A study compared the eye fixation in the reading of English and Chinese texts. The results showed that the eye fixation for each Chinese character was 0.26 second, that is, about 230 cpm (60/0.26), and that the eye fixation for each English word was 0.27 second, that is, about 222 wpm (60/0.27)

[12]. Furthermore, it was pointed out in the research related to dynamic display for Chinese text that when RSVP and the display speed of 140 cpm were employed in the 20-character single-line screen, participants had a significantly higher reading comprehension than in the case of 250 and 350 cpm. When the display was in the manner of leading, the display speed of 195 cpm showed a significantly better reading comprehension [13]. Chen and Chien [2] compared the effects of three different display speeds (171, 250, and 305 cpm) on three different screen sizes. As was revealed by the research, the display speed of 250 cpm was ideal for a laptop screen for reading comprehension. And the display speed of 305 cpm could be adopted for the screens of PDA and mobile phones. However, when Lin and Shieh [8] conducted the research with three display speeds (120, 240, and 500 cpm), they discovered that participants exhibited no significant differences in recalling the materials read when the display speeds were 120 and 240 cpm, though a display speed of 500 cpm greatly affected the participant's recalling rate.

1.4 Task Type

In the past studies concerning the reading in dynamic display, the consideration only focused on participants performing a single task, that is, the exploration of the effects of dynamic-display design factors upon the reading comprehension while concentrating on reading the dynamic text messages [1], [2], [3], [6, [7], [8], [10], [11], [13]. This study, in contrast, explored the effects of design factors on the participant's reading comprehension when they are engaged in one single task or when they are engaged in dual tasks.

2 Methodology

2.1 Participants

Twenty four native Chinese speakers from Taiwan participated in this study. Fourteen were females and ten were males between the ages of 19 to 36 with the average age 23.6 years (*SD*=3.16). All the participants were pretested to confirm that they had at least 20/25 visual acuity with corrective lenses if required.

2.2 Apparatus and Materials

Testing was conducted on a Pentium IV PC, with all text materials displayed on a 1024 × 768 resolution 17-in. LCD color monitor. Macromedia Flash 8.0 was used to simulate the SPOT watches available in the market. The testing interface simulated in the experimental design was placed right on the center of the monitor's screen.

The Chinese message texts read by participants consisted of 12 passages to be used in the formal experiment and 6 passages for practice. The passages came from the world encyclopedia, with 30 characters for each passage. The determination of Chinese words was based upon the research of Liu et al. [9].

In addition, according to relevant studies, the experimental design for the dual-task operation could be carried out by means of mental arithmetic [14]. The mental arithmetic was conducted via text-to-speech voice.

2.3 Experiment Design

This experiment was designed in order to determine the participant's reading comprehension of the dynamically displayed Chinese under the single- and dual-task conditions, respectively. The three factors likely to affect dynamic display, dynamic-display type, presentation method, and display speed, were explored in this study. The types of dynamic display were divided into two levels: leading display and RSVP. The two levels of presentation methods were character-by-character and word-by-word formats (Fig. 2). Display speeds were set up at 150, 250, and 350 cpm. Participants were tested under two task-type conditions: single- and dual-task conditions. In the dual-task conditions, participants would listen to and then work on a mental-arithmetic task at the same time that they were reading the dynamically displayed texts. There were altogether four variables: three design factors for dynamic display and the different task types among them, which were the dynamic display format, the

Fig. 2. Two presentation methods displayed in two dynamic displays were used in this study, (a) character-by-character format in an RSVP, (b) character-by-character format in a leading display, (c) word-by-word format in an RSVP, and (d) word-by-word format in a leading display

task type belonging to between-subjects design, and display speeds and presentation methods belonging to within-subjects design. Thus, the 24 participants were randomly divided into four groups: leading single-task group (LS), leading dual-task group (LD), RSVP single-task group (RS), and RSVP dual-task group (RD), with six participants in each group.

2.4 Procedure

Participants in the two single-task groups (LS and RS) began with a practice reading of the six short passages, which were presented in different combinations. Participants in the two dual-task groups (LD and RD) would listen to and then would work on the mental-arithmetic task at the same time as when they were practicing reading of the six passages. They would then rest for two minutes before proceeding to the reading of 12 short passages in the LS and RS groups respectively. The simultaneous reading of 12 short passages and calculation of the mental-arithmetic tasks by the LD and RD groups would occur. The short passages, mental-arithmetic tasks, display speeds, and presentation methods were all randomly arranged. Participants in each group would be subjected to six experimental treatments, with each treatment displayed twice. After the participants in the single-task group read a short passage, they would answer two questions according to the content of the passage. Participants in the dual-task group would also fill in the answers for the mental-arithmetic tasks. The whole experiment lasted about 30 minutes.

2.5 Analysis

The measurement of dependent variables for the experiment was conducted through the analysis of variance (ANOVA). The reading comprehension scores and mental-arithmetic scores were counted as dependent variables. The results were tested with α=0.05 as the standard for significant difference. If significant differences were observed for independent variables, Tukey HSD (honesty significant difference) would be employed to determine the level differences between the independent variables.

3 Results

3.1 Effects of Dynamic-Display Variables on the Participant's Reading Comprehension in the Single-Task Condition

Table 1 showed the comprehension scores and the standard deviations obtained by the design factors of various dynamic displays from each level when participants were carrying out a single task.

The ANOVA indicated no significant difference between the two dynamic displays. However, there was a significant difference between the two presentation methods (F (1,204) =14.182, p<0.01). The participant's reading comprehension from the word-by-word presentation method was significantly better than that from the

Table 1. The mean of comprehension score under each level of the independent variables for accomplishing a single-task

Independent variables	*n*	Mean (*SD*)	Tukey grouping [a]	
Dynamic text				
Leading	108	0.792 (0.322)		
RSVP	108	0.722 (0.364)		
Presentation method [b]				
Character-by-character	108	0.671 (0.375)	A	
Word-by-word	108	0.843 (0.287)		B
Speed				
150 cpm	72	0.799 (0.343)		
250 cpm	72	0.708 (0.333)		
350 cpm	72	0.764 (0.356)		

[a] values with the different letter are significantly different.
[b] significantly different at $\alpha < 0.01$ level.

character-by-character presentation method. Furthermore, the ANOVA demonstrated no significant differences between the three display speeds. There were also no interactions observed among the design factors of dynamic display.

3.2 Effects of Dynamic-Display Variables on the Participant's Reading Comprehension and Mental-Arithmetic Score in the Dual-Task Condition

Table 2 showed the comprehension scores and the standard deviations obtained by the design factors of various dynamic displays from each level when participants were undertaking dual tasks.

Table 2. The mean of comprehension score under each level of the independent variables for accomplishing a dual task

Independent variables	*n*	Mean (*SD*)	Tukey grouping [a]		
Dynamic text					
Leading	108	0.652 (0.375)			
RSVP	108	0.639 (0.341)			
Presentation method [b]					
Character-by-character	108	0.551 (0.361)	A		
Word-by-word	108	0.713 (0.336)			B
Speed					
150 cpm	72	0.708 (0.333)	A		
250 cpm	72	0.653 (0.342)	A	B	
350 cpm	72	0.535 (0.378)		B	

[a] values with the different letter are significantly different.
[b] significantly different at $\alpha < 0.01$ level.

The ANOVA revealed no significant difference between the two dynamic displays. However, there was a significant difference between the two presentation methods ($F(1,204) = 12.243$, $p=0.001$). The participant's reading comprehension from the word-by-word format was significantly better than that from the character-by-character format. Furthermore, the ANOVA revealed significant differences between the three display speeds ($F(1,204)=4.887$, $p=0.008$), the speed group of 150 and 250 cpm registered significantly better results than the speed group of 250 and 300 cpm. There were no interactions observed among the design factors for the dynamic display discussed above.

When participants performed dual tasks, they would listen to and work on mental-arithmetic tasks at the same time as when they read dynamically displayed texts. The ANOVA showed that there were no significant differences between the influences of the dynamic-display design factors upon the participant's mental-arithmetic results. There were also no interactions among these factors.

4 Discussion

There was no significant difference between leading display and RSVP in both single- and dual-task conditions. The results were similar to the studies involved in the comparison of leading display and RSVP [2], [7]. However, research pointed out that the participant's reading accuracy was significantly better in RSVP than in the leading manners [6]. The possible reason for the discrepancy in results might be due to the fact that the leap-type of leading display was adopted for the research. Because when participants were reading the text displayed in the manner of leap-type leading, the position of their eye fixation changed in accordance with the leaping distance of words which were presented in a flashing manner as these words were. On the contrary, the smooth-slide type of leading display involved the smooth movement of words and did not cause flashing. Therefore, a smooth-slide type of leading display was better than a leap-type of leading display. Moreover, Lin and Shieh [8] compared smooth-slide type of leading display and via RSVP on a 7×1.2 cm display screen for the participant's reading of written messages. It was found that, when compared with the eight-character single-line display in RSVP, participants achieved greater recall accuracy in the character-by-character and word-by-word formats of smooth-slide leading display. But no significant differences were registered when the comparison was made with word-by-word RSVP display. Thus, it could be concluded that whether the dynamic display was good or not should be determined by judging how the dynamic display factors were combined.

This study showed that the word-by-word presentation method was superior to the character-by-character presentation method for the reading of dynamic text on a wrist watch, no matter whether it was in the single- or dual-task conditions. Lin and Shieh [8] also discovered that the word-by-word presentation method brought about greater recall accuracy, either in the manner of leading or RSVP.

As is shown in this study, when participants conducted the single task of reading dynamic text on a wrist watch, the choice of display speed did not have much effect on

the reading comprehension. This result is similar to the related study [2], [8]. However, Wang and Chen [13] pointed out that when dynamic text was employed on the twenty-character single-line screen, display speeds lower than static display were needed to achieve better reading comprehension. In the course of reading, there was a limitation to the number of characters processed at each time of eye fixation (or perceptual span). Inhoff and Liu [5] claimed that the perceptual span in Chinese reading was about 3 to 4 characters on the right of the fixation point and about 1.5 to 2 characters on the left of the fixation point. In the research conducted by Wang and Chen [13], the presentation of twenty characters at a time was larger than the users' perceptual span at each fixation. The wrist-watch interfaces in this study presented a maximum of six Chinese characters, a number that was close to the normal span of each eye fixation in Chinese reading. This lowered the participant's times of eye fixations and saccades in reading. As a result, higher display speeds could be employed for the reading of dynamic texts on the small screen interface of a wrist watch. This also gives a possible reason for the difference between this study and that of Wang and Chen [13].

On the other hand, when participants were performing dual tasks at the same time, display speed was an important factor in affecting reading comprehension. The lower display speeds of 150 and 250 cpm were significantly better than that of 350 cpm. As users were limited in their concentration resources, the simultaneous performing of two tasks or more is likely to cause distraction, which can increase the cost of concurrence for cognitive resources. As a result, lower display speeds should be adopted for dynamic display in dual-task conditions so that the burden on cognitive resources would be lessened.

5 Conclusions and Future Works

The summary was made as follows with regard to the application of various dynamic-design factors to the reading of Chinese texts dynamically displayed on a wrist-watch interface: (1) Both smooth-slide types of leading display and RSVP can be applied to the wrist-watch interface for the presentation of written messages. The design of the interface can employ different dynamic displays in accordance with the different interface configuration requirements. (2) The presentation method of word-by-word format should be adopted for the reading of dynamic text on the wrist watch. (3) When users are involved in a single task, the higher display speed of 350 cpm can be adopted; but when users are performing dual tasks, the lower display speeds of 150-250 cpm are preferable.

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