Presentation of Personal Health Information for Consumers: An Experimental Comparison of Four Visualization Formats

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Abstract. While the development of consumer-oriented health information technologies (CHITs) has led to increased availability and accessibility of personal health information, consumers may encounter difficulty in comprehending the information, partly due to inappropriate information presentation. This study was conducted to compare four visualization formats of personal health information in consumers' use and comprehension of the information. A within-subjects design was employed, with visualization format serving as independent variable, and sets of user performance, perception, eye movement and preference measures serving as dependent variables. Twenty-four participants were recruited in this study. The results indicated that there was no significant main effect of visualization format on task completion time and accuracy rate, while visualization format yielded a significant effect on perceived health risk, perceived ease of understanding, perceived usefulness, perceived confidence of comprehension, and satisfaction. Participants' visual attention, indicated by eye movement measures, was significantly affected by areas of interest, but not by visualization format. Most participants preferred personalized enhanced format. Our study demonstrates that visualization formats could affect how personal health information are comprehended and perceived. The results may help to improve the design of more usable and effective health information presentation.

Keywords: Visualization format · Health information · Comprehension
Presentation

1 Introduction

The healthcare domain is facing great challenge due to increasing demands on healthcare services from people with chronic diseases and suboptimal health status, and the ageing population. In China, 300 million people are suffering from various chronic diseases [1], 1030 million people are experiencing suboptimal health status [2] and 220 million people are aged 60 years or above [3]. Research has shown that one of effective approaches to meet consumers' healthcare demands is continuous self-monitoring of health indicators

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(e.g., heart rate, blood pressure and blood glucose), which can be facilitated by consumer-oriented health information technologies (CHITs) [4–6]. CHITs refer to consumer-centered electronic tools, technologies, applications, or systems that are interacted with directly by health consumers (i.e., individuals who seek or receive health care services) to provide them with data, information, recommendations, or services for promotion of health and health care [4, 6]. CHITs are convenient tools to track, record and manage consumers' personal health information (e.g., blood pressure), and can easily present the information for a wide range of consumers [7–9].

While the development of CHITs has led to increased availability and accessibility of personal health information, consumers may encounter difficulty in comprehending and thus correctly responding to the information, partly due to inappropriate information presentation [10–12]. This is a significant concern in health care, as inappropriate presentation of health information may lead to confusion, frustration and disruption in consumers' healthcare process [13, 14] and even to adverse consequences, such as medication error and inappropriate healthcare decision-making [15, 16]. In fact, there is much evidence that consumers find it difficult to understand quantitative health information [17–19]. This is especially the case for people with low numeracy and literacy skills [20, 21]. While many consumers are in urgent need of understanding their health status, we know little about optimal presentation of personal health information for them.

The way health information presented can have significant influence on what the information is processed, a phenomenon known as the representational effect [22]. It has been increasingly recognized that the use of visualization may be an effective way to present quantitative health information, and is likely to improve interpretation and comprehension of the information [11, 23]. For example, Torsvik et al. found that visualization formats, such as sparklines and relative multigraphs, seem to be favorable techniques for presenting complex long-term clinical test results, while tables seem better for simpler test results [11]. However, until relatively recently, there has been little research to inform which kinds of visualization formats are optimal to support consumers' use and comprehension of personal health information. There is also a lack of research to describe how consumers perceive different visualization formats for their personal health information (e.g., whether a particular type of visualization format is perceived helpful or not in their healthcare).

The purpose of this study was to evaluate four visualization formats in consumers' use and comprehension of personal health information. The visualization formats were applied to two types of personal health information, i.e., blood pressure and blood glucose, which are main indicators that are usually monitored by chronically ill patients (especially those with hypertension and/or diabetes) [5, 7].

2 Methods

2.1 Experimental Design

A within-subjects design was employed, with visualization format (Four types: basic format, color format, color/text format and personalized format) serving as an independent variable, and sets of user performance (i.e., task completion time and accuracy

rate), eye movement (i.e., time to first fixation and total fixation duration), perception (i.e., perceived health risk, perceived ease of understanding, perceived usefulness, perceived confidence and satisfaction) and preference measures serving as dependent variables. Task completion time referred to the total time a participant spent to answer question in a specific task. Accuracy rate was calculated as the proportion of answers that were correctly answered for one type of visualization format. Eye movement measures were assessed to examine visual attention during task performance and were recorded using a Tobii X-120 eye tracker (Tobii Technology, Sweden). User preference was assessed by asking participants to choose their most preferred visualization format.

2.2 Participants

Twenty-four students (12 males and 12 females; mean age 22.1 years (SD 2.4)) participated in this study. They all had self-reported normal color vision and basic numeric knowledge and literacy. A minimal sample size of 17 was required to detect a medium effect size of 0.3 between visualization formats when statistical power and level of significance were selected at 80% and 5%, respectively. The study protocol was approved by the Institutional Review Board of Shenzhen University. Informed consent was obtained from each of the participants.

2.3 Materials and Tasks

All the four visualization formats were applied to results for two types of self-monitoring tests. self-monitoring of blood pressure presented results for diastolic and systolic blood pressure, while self-monitoring of blood glucose presented results for fasting blood glucose and two hours postprandial blood glucose.

All the four visualization formats were created based on horizontal bar graphs, which are commonly applied for displaying individual test results [10, 13]. Information presented in the visualization formats included test name, exact test value, unit of measurement, and cut-off points for normal range. Reference information of normal range for the test results was provided and put at the bottom of the graphs. The four visualization formats were described as follows. Basic format used non-color bar only. Color enhanced format applied color on the basic format, with green and red indicating normal and abnormal range, respectively; but the color meaning was not explained. Text/color enhanced format, based on the design of color enhanced format, provided explicit text explanation for the color to indicate whether the test result was normal or not. Personalized enhanced format, based on the design of color/text enhanced format, provided additional personalized information that was assumed to be an average value of the test results from population with the same sex and age as the participants (See Fig. 1 for an example). Four areas of interest (AOIs) were drawn for each graph to examine participants' visual attention. The first three AOIs covered area that presented different information from basic format, while the fourth one covered the area of reference information of normal range.

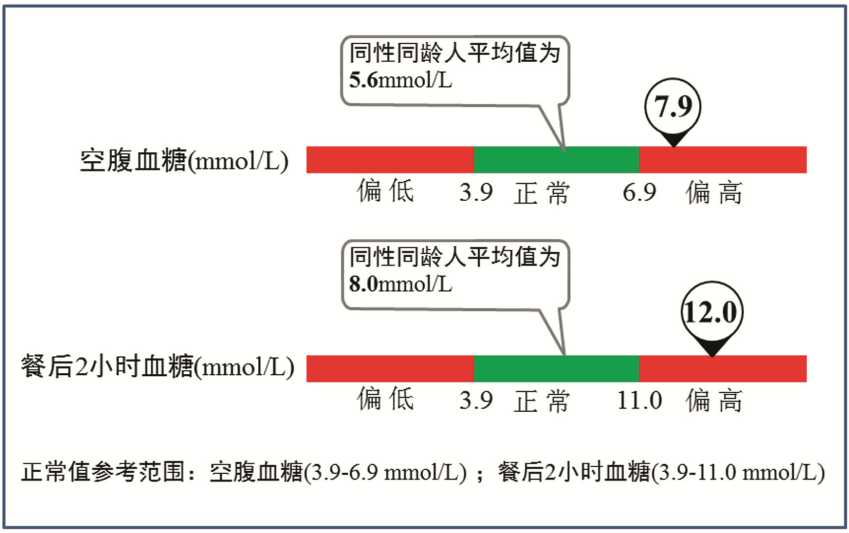

Fig. 1. Example of personalized enhanced visualization format for test results of self-monitoring of blood glucose. (Color figure online)

The experimental test included two types of tasks. Information search tasks asked participants to answer the exact test value present on the visualization format, while judgement tasks required participants to indicate whether the test value was normal or not.

2.4 Procedures

Task scenarios were performed on a DELL computer (Screen size: 23 inches; resolution: 1024×768). The eye tracker was equipped at the lower edge of the computer screen. Before the experiment, participants provided informed consent and were given detailed information of test procedures. The participants were then instructed to sit at a fixed distance from the computer screen, and to follow standard eye tracker calibration procedures. Following several practice tasks to familiarize themselves with the test, participants were asked to initiate the main experimental tasks. Participants were asked to respond as quickly and accurately as possible. Combinations of visualization format, and type of test were randomized in a full factorial design. After the experimental tasks, participants were required to complete a paper-based questionnaire to elicit their response to perception measures and preference. The whole experiment took approximately 40 min.

2.5 Data Analysis

Repeated measures analyses of variance (ANOVAs) were used to analyze the effects of visualization format on user performance, eye movement, and perception measures. Past

hoc analyses were performed with Bonferroni adjustment where necessary. Chi-square test was performed to examine the difference in user preference. Level of significance was set at $\alpha = 0.05$. Statistical analyses were performed using SPSS 22.

3 Results

3.1 Performance Measures

Table 1 presents ANOVA analysis results for task completion time and accuracy rate. There was no significant main effect of visualization format on task completion time ($F(3, 60) = 2.09$, $p = 0.111$) and accuracy rate ($F(3, 60) = 1.31$, $p = 0.280$) in information search tasks. Similarly, visualization format had no effect on task completion time ($F(1.947, 38.938) = 1.48$, $p = 0.240$) and accuracy rate ($F(1.679, 33.579) = 1.16$, $p = 0.331$) in judgement tasks.

Table 1. Effects of visualization format on task completion time and accuracy rate.

Visualization format	Task completion time (s)				Accuracy rate (%)			
	Descriptive analysis		ANOVA		Descriptive analysis		ANOVA	
	Mean	SD	F value	p value	Mean	SD	F value	p value
Information search task								
Basic	14.5	5.0	2.09	0.111	88.7	0.3	1.31	0.280
Color	14.6	5.3			89.6	0.3		
Color/text	12.3	5.1			85.5	0.3		
Personalized	16.0	6.6			82.1	0.4		
Judgement task								
Basic	3.0	0.9	1.48	0.240	90.0	0.2	1.16	0.331
Color	3.1	1.3			93.0	0.2		
Color/text	2.6	0.6			88.8	0.2		
Personalized	3.2	1.2			87.1	0.2		

3.2 Perception Measures

Visualization format yielded significant effects on perceived health risk ($F(3, 60) = 2.97$, $p = 0.040$), perceived ease of understanding ($F(3, 60) = 19.84$, $p < 0.001$), perceived usefulness ($F(3, 60) = 14.72$, $p < 0.001$), perceived confidence ($F(2.275, 45.497) = 15.21$, $p < 0.001$), and satisfaction ($F(2.191, 43.815) = 47.37$, $p < 0.001$). Perceived health risk was higher for personalized enhanced format than for basic format. Formats with more information cues resulted in more perceived ease of understanding and perceived usefulness, and higher levels of perceived confidence and satisfaction (Table 2).

Table 2. Effects of visualization formats on perception measures.

Measures	Visualization format	Descriptive analysis		ANOVA	
		Mean	SD	F value	p value
Perceived health risk	Basic	3.3	1.0	2.97	0.040
	Color	3.4	1.1		
	Color/text	3.5	1.0		
	Personalized	3.8	1.2		
Perceived ease of understanding	Basic	3.3	1.8	19.84	<0.001
	Color	4.9	1.5		
	Color/text	5.6	0.8		
	Personalized	5.6	1.3		
Perceived usefulness	Basic	4.5	1.6	14.72	<0.001
	Color	5.5	1.6		
	Color/text	6.0	1.2		
	Personalized	6.4	1.1		
Perceived confidence	Basic	4.2	1.8	15.21	<0.001
	Color	5.4	1.6		
	Color/text	5.9	1.2		
	Personalized	6.3	0.9		
Satisfaction	Basic	3.0	1.7	47.37	<0.001
	Color	5.4	1.9		
	Color/text	6.2	0.8		
	Personalized	6.3	1.0		

3.3 Eye Movement Measures

Time to first fixation was significantly affected by AOI ($F(3, 21) = 4.87$, $p = 0.010$), but not by visualization formats ($F(3, 21) = 2.67$, $p = 0.074$) (Table 3). Both AOI 4 yielded longer time to first fixation than other AOIs. Similarly, total fixation duration was significantly affected by AOI ($F(3, 21) = 15.68$, $p < 0.001$) but not by visualization formats ($F(3, 21) = 2.11$,$p = 0.130$). AOI 1 obtained longer total fixation duration than other AOIs (all p's < 0.05).

3.4 User Preference

Table 4 shows the user preference data on visualization format. Most participants preferred personalized enhanced graph (70.8%, $\chi^2 = 15.75$, $p < 0.001$).

Table 3. Effects of visualization formats and area of interest on time to first fixation and total fixation duration.

Visualization format	Time to first fixation (s)				Total fixation duration (s)			
	Descriptive analysis		ANOVA		Descriptive analysis		ANOVA	
	Mean	SD	F value	p value	Mean	SD	F value	p value
Visualization format								
Basic	2.2	0.7	2.67	0.074	0.7	0.6	2.11	0.130
Color	2.7	2.3			0.7	0.7		
Color/text	1.7	0.5			0.5	0.3		
Personalized	2.7	1.4			1.0	1.1		
AOI								
AOI 1	1.9	0.8	4.87	0.010	1.1	0.7	15.68	<0.001
AOI 2	2.9	1.1			0.4	0.4		
AOI 3	2.6	1.6			0.6	0.5		
AOI 4	4.1	1.5			0.7	0.5		

AOI, area of interest.

Table 4. Distribution of participant preference by visualization format.

Visualization format	Percentage
Basic	0%
Color	8.3%
Color/text	20.8%
Personalized	70.8%

4 Discussion

CHITs have enabled consumers to get access to their own health records from various self-monitoring tests more frequently. However, poorly designed presentation of test results usually leads to misunderstanding and confusion for consumers, in inefficiency and disruption in their health care process, and in a higher likelihood of committing errors in their medical decision-making. In light of this, the present study evaluate four different visualization formats to explore optimal presentation of personal health information for consumers. This study demonstrates that there are differences between visualization techniques with respect to how personal health information are viewed, possessed and comprehended, and how fast and effectively the comprehension is made.

4.1 Primary Findings

Our study represents a rare attempt to evaluate various visualization formats for personal health information. On one hand, the results show that the presentation of self-monitoring results in different formats had different effects on how consumers evaluated the information. This is congruent with findings from previous studies [10, 11, 23–28].

Consumers considered visualization formats that contained more information cues more useful and easier to understand, and developed more confidence in understanding their self-monitoring results with such formats. In particular, formats that used color/text, or personalized information were favored most by consumers. The findings appear to confirm the effectiveness of color, text and personalized information cues in facilitating consumers' comprehension of self-monitoring results. For example, color format is able to provide consumers immediate and strong impression of whether test values were within normal ranges [11]. Similarly, text and personalized information may work as redundancy check, and thus are likely to support consumers' decision-making in their information comprehension.

One the other hand, we observed only little variation in task performance between basic format and three other formats. This may be due to that differences between the four formats were not sufficient to influence consumers' efficiency and effectiveness in performing healthcare tasks, as they were all designed based on similar graphs, with similar structure and layout. However, this may also imply that the use of varied additional information cues would not cause additional cognitive workload for consumers, though more information needs to be processed.

We found that consumers perceived higher risk for their health status, as more information cues were applied in the visualization formats. This may be that consumers became more cautious and conservative in the evaluation of their health information, and thus consider themselves in a higher risk level, as the visualization formats contained more information. However, it should be noted that there is little consensus regarding which level of health risk is appropriate and should be conveyed to consumers for certain health information. Thus, it remains unclear how information should be visualized to convey appropriate perceived health risk for consumers. Intriguingly,

The present study provided preliminary yet unique evidence on visual attention when consumers view the graphs, which is less investigated in previous studies but particularly important in the visualization of health information. We found that as more information cues were applied in the visualization formats, shorter time to first fixation and longer total fixation time were observed in corresponding AOIs, indicating an attraction effect of information cue. The attraction effect was especially obvious when the color cue was introduced. Moreover, we observed that reference information was less noted. Also, for those who noted the information, it took them longer time to do so. This implies that the current presentation of reference information might need revision, as it was even not noted by consumers. More efforts are required to design innovative ways to present test results and reference information together in a holistic way.

While the importance of user experience measures, such as subjective perceptions and preference, is increasingly recognized in the design of informatics tools, they are largely overlooked in existing literature and information visualization guidelines [29]. This study demonstrated that the majority of participants preferred personalized visualization format. It appears that users favored presentation format that was able to convey better perceptual feelings. User preference is important, as users may largely base their decision of using certain informatics tools on subjective perceptions and preference. Therefore, researchers and practitioners should pay sufficient attention to user preference

in future revision of information visualization guidelines in addition to performance and perception measures.

4.2 Implications

Our findings have important implications for the visualization of personal health information for consumers. Theoretically, our study emphasized the importance of appropriate design of visualization format to improve consumers' performance and comprehension of health information. From a practical perspective, our results are not clear on what is the optimal visualization format for personal health information with respect to how quickly the results could be correctly interpreted. Rather, our study shows advantages and disadvantages of different visualization formats. Providers and designers need to be aware of the differential effects on consumers' comprehension, perceptions, visual attention and preference that may be generated through the use of different visualization formats.

4.3 Limitations

This study has several limitations. First, the generalizability of our findings remains to be established. Our conclusions about the effects of visualization format should be viewed as tentative, as only a limited number of visualization formats were evaluated in our study with a small sample size. Second, while our study was conducted in a controlled laboratory, it did not fully simulate actual use of personal health information. This approach may lead to limited ecological validity of the findings. It is likely that participants might respond differently in a real situation. Finally, we did not address age-related factors, such as health literacy, graph literacy, and cognition ability, which are suggested to affect comprehension [28, 30]. Studies with chronically ill patients, or people with low health literacy and education level may yield different results.

5 Conclusions

It is essential for consumers to accurately comprehend personal health information in their healthcare activities. This study demonstrated that different techniques for visualizing and presenting personal health information influenced on how the information was assessed, perceived and comprehended. More development has to be undertaken to improve the visualization techniques and examine them in practical settings where consumers actually use them in real self-care activities.

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