Effectiveness of Tactile Scatter Plots: Comparison of Non-visual Data Representations

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Abstract. The goal of making a scatter plot is to visually identify the type of relationship between two quantitative variables quickly. To explore whether a scatter plot can achieve this goal when it is made in the form of a tactile graph and presented to blind people, we conducted an experiment in which *x-y* data sets were presented to blind participants in three data representations: tactile graph, tactile table, and electronic table, and the participants were asked to identify the type of relationship between two variables. Under all presentation conditions, the correct rates were high: it was 92.5% for the tactile graph condition and 85.0% for the tactile table and electronic table conditions. Tactile graphs were understood with the shortest time, tactile tables with the second shortest, and electronic tables needed the longest time. This differences were due to the different strategies for identifying the relationships. Both tactile graph and tactile table conditions gained higher subjective ratings than the electronic table condition.

Keywords: Blind people · Tactile graph · Tactile table · Screen reader Scatter plot

1 Introduction

In everyday life, we often discuss the relationship between two quantitative variables such as heights and weights, temperature and ice cream sales, and working hours and accepted papers. To visually identify the type of relationship between two quantitative variables quickly, scatter plots are usually used. For blind people, visual graphs are transformed into a tactile form. Our research question is whether a scatter plot can achieve its goal when it is made as a tactile graph and presented to blind people. To explore this issue, we conducted an experiment in which twelve *x-y* data sets were presented to 10 blind participants in three data representations: tactile graph, tactile table, and electronic table, and the participants were asked to identify the type of relationship between two variables. We measured the reading time and correct rate, recorded the reasons for identifying reported by the participants, and discussed the effectiveness of tactile scatter plots based on these experimental results. The data for the first three participants were reported at ICCHP 2012, where the trend that the

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relationships were identified the fastest with tactile graphs among three data representations was shown [1]. In this report, we added seven more participants and observed this trend statistically.

2 Related Work

A few studies have been conducted on the readability of tactile graphs. Goncu et al. investigated the effectiveness of grid lines in tactile bar charts and found that adding grid lines and values to a bar chart was preferred [2]. Additionally, they compared four data representations, horizontal tactile bar charts, vertical bar charts, tactile tables, and vertical bar charts with audio description. The blind participants preferred tactile tables over tactile charts. Watanabe and Inaba explored which texture was suitable to fill tactile bars on capsule paper [3]. As the result, black and dark gray colors and the dot patterns whose inter-dot spacings were 1.5 mm or less were found to be suitable in terms of exploring times and subjective ratings. Yu and Brewster compared virtual haptic bar charts and conventional tactile bar charts on paper in terms of correct rate, reading time, and mental workload [4]. The result was that the number of correct answers was significantly higher with the virtual haptic system, but more reading time was spent with the system which led to significantly heavier workload.

Araki and Watanabe compared the accuracy of reading tactile pie charts and reading tactile band charts with sighted and blind students as participants [5]. They were presented with a set of tactile pie charts and band charts with individual division ratios and asked to answer the ratio. The results from sighted participants showed that the error sizes in reading pie charts were smaller than those in reading band charts and that there was little difference between the reading times of the two charts. The results from a blind participant showed similar trend to those from sighted participants except for the reading times.

Engel and Weber analyzed 69 tactile charts to develop design guidelines for tactile charts [6]. These tactile charts were collected from publications and tactile graphics guidelines. The types of these tactile graphs were bar charts, line charts, pie charts, area charts, and scatter plots. The first three chart types occupied 90% of the charts analyzed whereas scatter plots occupied merely 4%. This implies the low use rate of tactile scatter plots and, thus, researches on tactile scatter plots are scarce.

In this paper, we focus on tactile scatter plots and explore if tactile graphs are more useful than tactile tables or reading numerical data with a screen reader.

3 Experiment

3.1 Stimuli

For three data representation methods, tactile graph, tactile table, and electronic table, different data sets of four types of relationship, linear, quadratic, inverse proportion, and non-correlated, were assigned, thus in total 12 data sets were prepared. Each data set was comprised of 20 x values, and 20 y values. For all of the 12 data sets, the x values ranged from 0.5 to 10 by 0.5 step. For the nine data sets, *y* values were determined in the following two steps. First, the *y* values were calculated by inputting the *x* value into one of the three functions, linear, quadratic, and inverse proportion functions. Then, errors up to 10% of each y value were added in order to imitate observed (not idealistic) data and to prevent the participants from easily calculating *y* values from the *x* values and the functions. The error values were determined based on the values calculated by the random function of Microsoft Excel. The non-correlated data were also produced using the random function. The range of y values of all the data sets was from 0 to 120.

The tactile graphs and tactile tables were made with a braille embosser (ESA 721, JTR), the most popular embosser in Japan [7]. The dimension of all the tactile graphs was 147 × 200 mm (width x height). Electronic tables (text files) were voiced with a screen reader (either of PC-Talker, JAWS, or VDMW) that worked on a laptop personal computer with Windows 7 operating system. Three types of data representations are shown in Fig. 1.

	A	B
1	xとyのかんけい 1	
2		
3	x	y
4	0.5	4.7
5	1	8.2
6	1.5	16.8
7	2	19.7
8	2.5	20.9
9	3	34.3
10	3.5	36.3
11	4	47.7
12	4.5	45.6
13	5	54.2
14	5.5	65.6
15	6	67.6
16	6.5	62.7
17	7	63
18	7.5	87.3
19	8	83.3
20	8.5	75.5
21	9	99.9
22	9.5	101.8
23	10	113.7

Fig. 1. A tactile graph (left), tactile table (middle), and electronic table (text file, right) used in the experiment.

3.2 Participants

Participants were 10 blind people aging from 19 to 27 with an average of 22.0 years. All of them had a grade 1 disability (mostly totally blind) and used braille every day. All of them had learned mathematics by means of braille textbooks including tactile graphs at a school for the blind.

3.3 Procedure

The experiment was carried out in a quiet room one by one. The participant sat on a chair in front of a table and touched the stimuli (tactile graphs and tactile tables) and used a personal computer on the table.

Prior to the experiments, the explanation of the four relationships' features was given to the participant. They were notified in advance that each data set had errors and differed from idealistic values.

For each presentation condition, four stimuli representing one of the four relationships were presented to the participant all together. The participant was allowed to touch the tactile graphs or tactile tables or use the computer freely until they understood all the relationships of the four stimuli. Then, they were instructed to report the answers and to explain the reason(s) for answering so. The experimenter used a stopwatch to measure the time from the start of touching the stimuli or using the computer to the start of answering as reading time.

To read an electronic table, five participants used their own laptop personal computer (OS: Windows 7) and the other five used a laptop personal computer that the experimenters prepared (Vostro 1500, Dell. OS: Windows 7. Screen Reader: PC-Talker 7).

There were six permutations to present three conditions. To each permutation, two or one participant(s) was/were assigned.

After the three representations were tested, the participant was instructed to rank the readability of each representation, from one: most readable to three: least readable, except for the first three participants.

4 Results

4.1 Reading Time

The reading times for the three representation conditions averaged over the 10 participants are shown in Fig. 2. Tactile graphs were understood with the shortest time, tactile tables with the second shortest, and electronic tables needed the longest time. As the time differences among the participants and among the representation conditions were very large, we used a nonparametric Friedman test and found a significant difference in the reading time among the representation conditions ($S = 9.8$, $p < 0.01$). As pairwise comparison tests, the Wilcoxon signed-rank test with the Ryan's method was repeatedly used. The tests showed significant differences between tactile graph and electronic table conditions.

4.2 Correct Rate

The correct rates for the three representation conditions averaged over the 10 participants are shown in Fig. 3. It shows a ceiling effect. For six out of 10 participants, the correct rate was 100% for all the three representation conditions. Overall correct rate was 92.5% for the tactile graph condition and 85.0% for the tactile table and electronic table conditions. A Friedman test did not reveal a significant difference in the correct rate among the representation conditions ($S = 0.6$).

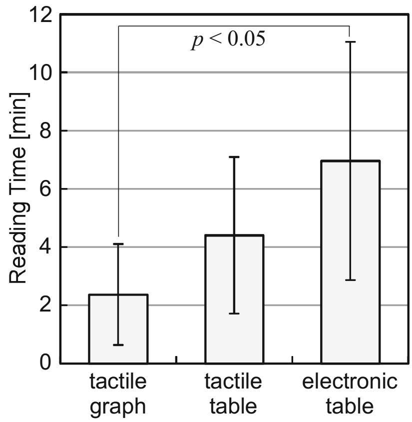

Fig. 2. Reading time.

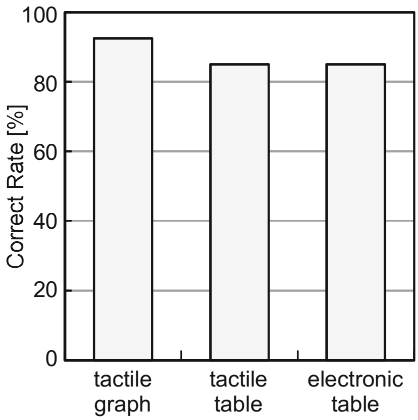

Fig. 3. Correct rate.

4.3 Reasons for Identifying

In the experiment, the participants were instructed to report the reasons for identifying the four relationships. As a result, the characteristics that distinguished each relationship from the others and the methods to find such characteristics under each representation condition were collected. Linear and quadratic functions had some characteristics in common. Tactile tables and electronic tables had some methods in common. The characteristics that distinguished each relationship are listed in Table 1.

Out of these characteristics, the plot arrangements were perceived under the tactile graph condition (in Table 1, "TG" cells are marked with *) and the ratios and differences were calculated under the tactile table and electronic table conditions (in Table 1, "Table" cells are marked with *).

Table 1. Observed features of each function. TG is the abbreviations for tactile graph and Table means both tactile and electronic tables.

Functions	Characteristics	TG	Table
Linear and quadratic functions	As x grows larger, y grows larger, i.e. the graph line runs from lower left to upper right	*	*
Linear function	Plots distribute linearly	*	
	The ratio of y to x is mostly constant		*
	Differences between neighbouring y values are mostly constant		*
Quadratic function	Plots approach the x axis (i.e. y values approach zero) as x values become close to zero	*	
	As x grows larger, the ratio of y to x grows larger		*
	Differences between neighbouring y values become larger as x grows larger		*
Inverse proportion	Plots approach the x axis (i.e. y values approach zero) as x becomes larger	*	
	As x grows larger, y grows smaller	*	*
	Y is very large when x is close to zero		*
	Differences between neighbouring y values are very large when x is close to zero		*
	Differences between neighbouring y values become smaller as x grows larger		*
Non-correlated	Plots distribute randomly	*	
	It felt as if there were multiple grahps or it were a circle	*	
	Differences between neighbouring y values are unstable		*

4.4 Subjective Rating

The subjective ratings for the three representation conditions averaged over the seven participants are shown in Fig. 4. The longer the bar is, the higher the subjective rating is. Both tactile graph and tactile table conditions gained higher ratings than electronic table condition. However, a Friedman test did not show a significant difference in the subjective rating among the representation conditions (S = 5.4).

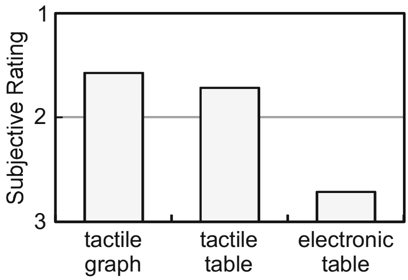

Fig. 4. Subjective rating.

5 Discussion

For the correct rate, a ceiling effect was observed and the differences among the three conditions were small (Fig. 3). Contrastingly, for the reading time, a significant difference were observed among the three conditions (Fig. 2). Thus, in this section, the differences in reading time are discussed based on the reasons for identifying four relationships.

The differences in reading time between the tactile graph condition and the two table conditions stemmed from the different strategies for identifying the four relationships. As described in the result section, under the tactile graph condition, the plot arrangements were tactually perceived very quickly. On the other hand, under the two table conditions, the ratios and differences had to be calculated mentally. This strategy needed quite a time because the calculation had to be repeated until the characteristics of the relationships were understood. Additionally, understanding the characteristics was hindered due to the errors included in the data.

Though the difference was not significant, the reading times under the tactile table condition were much shorter than those under the electronic table condition. When reading the table data, moving fingers to the next line or column took shorter times than pressing the arrow keys and listening to the speech on a computer. Moreover, with tactile tables two hands were available. This also speeded up the movement of the focusing cells.

6 Conclusion

The experimental results have shown that tactile graphs enabled blind people to identify the relationship between two variables more quickly than tactile and electronic tables. This was due to the difference in identifying strategies: To identify the relationship between x and y in tactile tables, the ratio of y to x and differences between neighbouring y values must be calculated repeatedly. On the other hand, the shapes of graphs can be understood tactually in shorter times.

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