Identifying how Visually Impaired People Explore Raised-line Diagrams to Improve the Design of Touch Interfaces

Sandra Bardot[1, 2], Marcos Serrano[1, 2], Bernard Oriola[2,1], Christophe Jouffrais[2,1]

[1] University of Toulouse – IRIT
Toulouse, France
{firstname.lastname}@irit.fr

[2] CNRS - IRIT
Toulouse, France
{firstname.lastname}@irit.fr

ABSTRACT

Raised-line diagrams are widely used by visually impaired (VI) people to read maps, drawings or graphs. While previous work has identified general exploration strategies for raised-line drawings, we have limited knowledge on how this exploration is performed in detail and how it extends to other types of diagrams such as maps or graphs, frequently used in specialized schools. Such information can be crucial for the design of accessible interfaces on touchscreens. We conducted a study in which participants were asked to explore five types of raised-line diagrams (common drawings, perspective drawings, mathematical graphs, neighborhood maps, and geographical maps) while tracking both hands fingers. Relying on a first set of results, we proposed a set of design guidelines for touch interfaces.

Author Keywords

Raised-line diagram; blind; tactile exploration; tactile maps; tactile drawings; bimanual exploration; finger tracking.

ACM Classification Keywords

H.5.2. User Interfaces: User-centered design. Input devices and strategies,

INTRODUCTION

Raised-line diagrams provide visually impaired (VI) people with access to graphs, drawings or maps [16]. Usually, they are hand-made because the content must be adapted and simplified. Moreover, they must be printed beforehand, which can be tedious and expensive in a teaching context. Then, it is pertinent to use digital versions of the diagrams that are accessible through adapted non-visual interactions.

Many approaches have been proposed, and can be summarized into three large categories. The first one consists in using refreshable displays that can dynamically raise up and down small pins providing a perceptible relief for manual exploration [20, 24]. A second category relies on tangible objects that represent important elements of a drawing, and can be linked to each other to render lines and areas [18, 4]. The last category consists in using finger tracking devices (touchscreens, cameras, etc.) to follow finger movement over a digital map, and render the content with auditory or vibrational feedback [2, 6, 5, 10, 25]. However, the process of converting physical content to digital cues is performed empirically. Understanding how VI people explore physical raised-line diagrams, and which elements are of importance, could help to design non-visual tactile interfaces.

In psychology, several studies aimed to assess the capacity to identify raised-line diagrams. In general, these studies compared tactile exploration of sighted, early and late blind people who had to recognize drawings of common objects (car, fruit, tool, etc.). For instance, Heller et al. [1] compared the blind and sighted children exploring raised-line drawings, and showed that they reach the same performance when sighted are guided during exploration. Lebaz et al. [13] showed that the performance depended on the type of common drawing being used in the study (“flat” 2D drawings, or with 3D cues). However, these studies mainly relied on identification rates, and did not inform about the hand movements that were used.

Our goal was to understand the main role: 1) of hands (and fingers) during raised-line diagrams exploration, according to 2) diagram type, and 3) user expertise. We used different raised-line diagrams including drawings, mathematical graphs, and neighborhood or geographical maps. We developed an experimental setup to track the fingers of both hands during tactile exploration. We recruited 6 visually impaired and 6 sighted blindfolded subjects who explored the diagrams. The results were based on accurate tracking of the exploration movements, and highlight different exploration patterns concerning the movement of both hands and the covering of the diagrams. They showed that performance was significantly different according to the diagram types and user profiles.

RELATED WORK

It has been shown that it is difficult to name tactile pictures for naive subjects [7]. It has also been shown that tactile recognition of drawings depends on previous visual experience. However, studies comparing tactile recognition rate of sighted, early and late blind people showed that blind people can either perform better (see e.g. [7]) or worse (see e.g. [14, 17]) than sighted people. In fact, it

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seems that the difficulty of picture recognition varies with complexity, familiarity, and categorical information [8, 9].

The procedures used to explore real 3D objects have an impact on the type and quality of information available [15], and affect the performance at haptic recognition tasks. Hence exploration procedures, but also the more general strategies combining these procedures, probably depend on the intended goal of the task. For instance, one might want to learn quickly as much as possible about an object, or alternatively test some hypothesis about that object. These general principles probably apply to the tactile exploration of 2D raised-line diagrams too. Recent studies depicted specific hand movements during the exploration of raised-lines diagrams with blindfolded participants [22]. They showed that, most of the time, subjects used their index finger(s), either alone or in combination with other fingers. Although subjects were usually unaware of how they moved their hands, the movements were both purposive and systematic [22]. Another study showed that both hands were used more than 83% of the time, which significantly increased identification of raised line drawings [23]. In fact these patterns of hand movement have been called exploratory procedures [19]. They include lateral motion (moving the fingers back and forth across a texture or feature), contour following (tracing an edge within the image), and whole-hand exploration of global shape [19]. However these different studies did not systematically depict exploratory procedures according to the drawing being explored or the task being performed [12].

Tactile exploration of a digital drawing on a touch-screen display is even more difficult [11]. Guerreiro et al. [6] focused on the observation of bimanual exploration (one finger of each hand) on large touchscreens during four specific tasks (locate, relocate, count, relate). They identified seven features and four strategies that appeared when visually impaired subjects were exploring drawings that resemble geographical maps with a few landmarks only. This work clearly showed that specific strategies appear in relation to the tasks being performed. However, the study relied on one map-like diagram only and did not consider other types of diagrams (e.g. common drawing or mathematical graph).

In the current study, we used a setup made of a touchscreen and a camera which allowed for accurate tracking of hands and fingers movements. Our method extends previous work [3] based on a depth-camera that could not accurately separate the fingers from the surface during tactile exploration. Our setup leverages quantifying the hand movements involved during the tactile exploration of different types of raised-line diagrams.

STUDY: EXPLORATION STRATEGIES

The goal of our study was to understand the role of each hand during the tactile exploration of different types of diagrams (drawings, graphs or maps) by users with different expertise (sighted blind-folded or visually impaired).

Raised-line diagrams

In psychology research, most of the studies concerning tactile exploration relied on common drawings [13, 21, 23]. But common drawings are not the most used diagrams by VI people. Indeed, in specialized schools, students have geography, math, and locomotion lessons, which rely on raised-line charts and maps. Hence, we selected five different types of diagrams (Figure 1). All the diagrams were made with the assistance of a professional tactile document maker. We also performed several iterations with VI users to refine height and width of the raised lines, as well as the legibility of Braille text. We designed three diagrams of each type, except for the Common Drawings (we used 10 of them, see task below). All the diagrams were printed in A3 landscape format on Zytech swell paper.

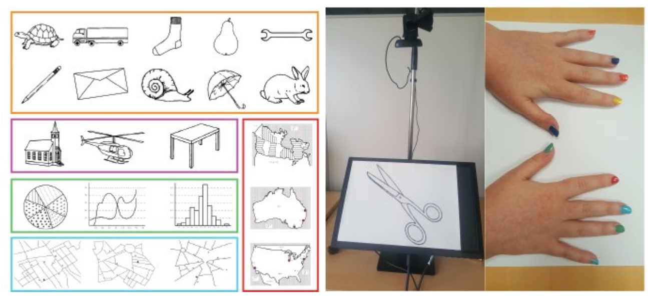

Figure 1. Diagrams used (left) and experimental setup (right): a raised-line drawing is placed over the touchscreen. A camera located above the drawing tracks fingers movements.

Common Drawings (C-Drawings) and Perspective Drawings (P-Drawings): they were issued from the Snodgrass and Vanderwart set of images [21]. Selected C-Drawings were: scissors, envelope, sock, open-end wrench, pencil, umbrella, truck, snail, turtle, rabbit, and pear. P-Drawings represented a couch, church, table, and helicopter. They included perspective cues.

Mathematical graphs (Graphs): We used graphs frequently used in specialized schools, i.e. histograms and plots.

Neighborhood maps (N-Maps): Delimited zone of a city. We added two itinerary points (starting and ending) as well as shops, represented by an empty triangle, a solid triangle, and filled circles, respectively.

Geographical maps (G-Maps): Two types of maps were included, representing a country with either a few main cities or the regions within the country. The cities were represented by solid points, with the first two letters written in Braille. Borders between regions were represented by dotted lines. A few regions included a different texture that emphasized a specific element. Seas and oceans were represented with a specific texture.

Tasks and instructions

During the study, each participant explored 22 diagrams: 10 Common Drawings, and 3 drawings of the four other types.

The study was divided in two steps. The first step consisted in identifying 10 C-Drawings as fast as possible (max time allowed: 90s). The drawing category was mentioned beforehand (e.g. object or animal). We measured the time needed to identify the drawing. The goal was to assess the expertise level of each participant in terms of raised-line diagram exploration. The second step consisted in the exploration of the four other types of diagrams by blocks of 3 trials (total of 12 trials). First, the participants explored a diagram for 30s (*free exploration*). Then, they had another 60s to explore the same diagram in order to answer a question (*driven exploration*). The questions varied according to the type of diagram: for P-Drawings, they had to identify the object among 4 choices. For Graphs, they had to find specific min and max values. For N- Maps, they had to find the number of stores between the starting and ending points. For G-Maps, they had to compare different regions. No instructions were given concerning the use of one or two hands.

Participants

We recruited two groups of participants: 6 sighted subjects who were blind-folded (BF, 3 females), and 6 visually impaired subjects (VI, 5 females). These two groups should show contrasted results because BFs are non-experts of tactile exploration but can rely on previous visual knowledge to identify drawings. In contrast, VIs are experts of tactile exploration but with very few, if any, previous visual knowledge. BFs were 2 university students and 4 staff members aged 27 on average (SD=2). VIs were 5 teachers and 1 radio-program presenter aged 46 on average (SD=14). Among them, 5 were early blind and 1 had very limited residual vision (light perception). She was blindfolded during the study.

Before the experiment, we conducted an interview to assess proficiency in braille reading and raised-line diagrams exploration (on a 5-points Likert scale). All VI participants rated their expertise between 2 and 5 (M=4,5) for Braille reading and between 1 and 4 (M=3) for tactile exploration. They all used their left hand as the main reading hand but differently: 1 read with left hand only, 5 with both hands. The 5 VI teachers explore raised-line diagrams several times per week. BFs had no prior experience with raised-lines diagrams.

Design and procedure

Our study followed a within-participants design, with one factor: Diagram type (C-Drawings, P-Drawings, Graphs, N-Maps, and G-Maps). The order of the last 4 blocks (1 block for each diagram type) was counterbalanced across participants. Within each block, the order of the 3 trials was random. Users were free to take a break between blocks.

Experimental setup

The subject was comfortably sitting in front of the tactile drawing placed over a 22-inch (1680x1050px) multi-touch screen (Fig. 1). We used a Logitech C270 webcam (1280x720 px) located above the touch screen in order to track the ten fingers according to colored markers placed on each nail (Fig. 1). The acquisition rates were 50 Hz for the camera and 100 Hz for the touchscreen.

Collected data

We collected the coordinates of the 10 fingers, as well as the touch status. We also measured the exploration time needed to answer the questions. In addition, subjects had to rate the difficulty for each type of diagram. At the end of the session, we asked them whether they were aware of using any specific exploration strategy. We also collected their subjective feeling about the number of hands and fingers they used, and why for.

RESULTS

We computed a Univariate ANOVA with a Bonferroni Pairwise post-hoc test to compare the results.

Exploration times and accuracy

We found main effects of diagram type ($F_{4,44}=6.9$, $p<.001$) and user group ($F_{1,11}=8.1$, $p=.005$) on exploration times. The averaged exploration times were 45.9s for BF participants and 39.4s for VI participants. Post-hoc comparison revealed a significant difference ($p<.001$) between C-Drawings (M=44.7 s) and P-Drawings (M=27.5 s) exploration times.

Concerning accuracy, we found a main effect of diagram type ($F_{4,44}=8.7$, $p<.001$) and an interaction between diagram type and user group ($F_{1,11}=8.7$, $p=.006$). Post-hoc comparison showed a significant difference between C-Drawings and N-Maps ($p=.002$) and C-Drawings and P-Drawings ($p<.001$). The accuracy per diagram type was (BF vs. VI participants): C-Drawings (58.6 vs. 41.3%); G-Maps (27.7 vs. 70.5%); Graphs (62.5 vs. 75%); N-Maps (11 vs. 31%); and P-Drawings (93.7 vs. 5%).

Diagram covering

We measured the covering for each type of diagram, i.e. the percentage of diagram that was explored. We found a main effect of diagram type ($F_{4,44}=4.5$, $p=.003$) and user group ($F_{1,11}=9.1$, $p=.003$) on covering. Post-hoc comparison showed a significant difference between C-Drawings on one side, and N-Maps ($p=.002$), G-Maps ($p=.002$), and Graphs ($p=.01$) on the other side. The averaged diagram covering was 65.7% for BF and 52.2% for VI participants. The covering per diagram type (BF vs. VI participants) were: C-Drawings (74.2 vs. 59.7%); G-Maps (51.6 vs. 44.1%); Graphs (52.3 vs. 51.1%); N-Maps (55.4 vs. 40.6%); and P-Drawings (75.7 vs. 46.1%).

Exploration distance per diagram and per hand

We measured the total exploration distance for each hand and diagram (Fig. 2 Left). We found an effect of the user group on the distance covered by the right ($F_{1,11}=61$, $p<.001$) and left hands ($F_{1,11}=17.5$, $p<.001$). For BF participants, the exploration distances were 460 and 727 cm for the left and right hand respectively. For VI participants, the exploration distances were 769 and 257 cm for the left and right hand respectively.

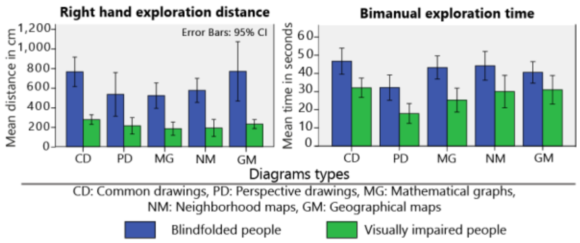

Figure 2. Left: Mean exploration distance for the right hand. Right: Time when both hands moved simultaneously (bimanual exploration).

Bimanual exploration

For each trial, we also computed the time during which both hands were moving simultaneously (bimanual exploration time; see Fig 2). We found an effect of diagram type ($F_{4,44}$=3.8, p=.004) and user group ($F_{1,11}$=27.5, p<.001). The bimanual exploration times were 43s (83.6%) and 28.7s (74.6%) for BF and VI participants respectively.

DISCUSSION

These results showed that VI subjects were faster than BF subjects when considering all the diagram types. They are similar to the results from [7], and probably reflect the greater expertise of VI subjects. However, another result is striking. Although BF and VI subjects reached the same overall identification performance (52%), the percentage of correct responses was significantly different according to the type of drawing. For instance, VI subjects reached 31% of correct responses on N-Maps whereas BF subjects only reached 11% correctness. In fact, VI subjects were better at exploring G-Maps and N-Maps. On the contrary, BF subjects were better at identifying C-Drawings and P-Drawings. This result confirms that exploration of tactile drawing depends on complexity, familiarity, and categorical information [8,9], but also shows that recognition depends on the type of drawing being explored, as well as the expertise of the user. It is probable that VI adults more frequently explore maps and mathematical diagrams than drawings of objects. In addition, drawings rely on visual conventions (occlusions and perspectives) that are less significant to VI people [7].

Our results also highlighted that VI participants covered a smaller exploration distance than BF for all diagram types (52% vs. 66%), although they got equivalent success rates. We observed that VI subjects focused on salient areas of the diagrams (such as the ears on the Rabbit drawing) to identify the diagram type, which made their exploration more efficient. Overall, Drawings required a more extensive exploration than Maps and Graphs.

Exploration distance per hand highlighted that VI and BL subjects had opposite hand behaviors: VI mainly used left hand (769 cm per trial), which is their braille reading dominant hand, while BL subjects used mostly right hand (727 cm). Interestingly, VI subjects covered a limited distance with right hand (257 cm per trial), and BF subjects spent more time performing bimanual exploration. This observation probably reflects that VI subjects appropriately use the second hand as an anchor that helps to understand the drawing, which is a valuable exploratory procedure.

DESIGNING INTERACTIVE ACCESSIBLE DRAWINGS

Our results confirm that VI people are able to explore tactile displays effectively but, depending on their own expertise or the type of diagram being explored, they may benefit from instructions or guidance. According to the format (A3) of the diagrams used in the current study, this preliminary work can provide general design guidelines for tactile displays larger than smartphone or tablet screens.

Touch robustness: Because participants laid their hand on the surface, we frequently observed more than ten simultaneous touch events (16 for BF and 17 for VI), corresponding to additional contacts with the palm. Then, although touch interfaces should enable more than two fingers for tactile exploration, they must prevent unexpected touch events, for instance by combining touch and camera tracking.

Content Simplification: A substantial amount of the raised-lines are not used for completing the different tasks. Then tactile drawings could be further simplified, but in a way that is specific to each type of drawing.

Multimodal Information Sharing: Common drawings require thorough exploration for identification. Then, interfaces may provide both contextual and local feedback (e.g. “rabbit” and “ears”). N-Maps raised exploration issues related to locating specific points. Then, interfaces may provide hand guidance cues (e.g. vibrotactile cues). In general, additional cues (e.g. sound or vibratory pattern) may highlight salient regions of the diagrams to facilitate exploration.

Interaction Menus: VI subjects mainly use their dominant hand for exploration. The non-dominant hand often stays steady, as an anchor. Hence, validation or selection commands could be assigned to the non-dominant hand. These commands should be contextual.

CONCLUSION AND FUTURE WORK

This preliminary study, as well as the general design guidelines that we provide, should be extended. The method can be used in the field of experimental psychology to better understand the role of each finger during tactile exploration. The method can also be used to address specific design questions according to the types of diagrams, tasks, and targeted users.

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