An evaluation of substrates for tactile maps and diagrams: scanning speed and user preferences

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Abstract

This study considers the relative suitability of a range of base materials for producing tactile maps and diagrams for visually impaired people via a new ink-jet process. Visually impaired and sighted participants scanned by touch symbol arrays printed onto seven different substrate materials, including papers, plastics and aluminium. Participants’ search times and preferences were recorded. In general, the rougher substrates were scanned faster than the smoother substrates. Moreover, the majority of participants preferred the rougher substrates over the smoother.

Introduction

Tactile maps and diagrams are raised-line images that are used to convey information in graphic formats to people with visual impairments. This information can be of great importance to visually impaired people, as it allows them to study, work and live more independently. Tactile images are produced using a variety of substrates (background materials), depending on the production method used (Horsfall, 1997; Morley & Gunn, 2002). For example, the microcapsule process uses cloth embedded paper that contains heat activated microcapsules, embossed graphics are produced using paper, thermoform uses thermoplastic polymers, and screen printing is done on a wax based paper.

Previous studies have attempted to measure differences in map reading performance between various methods. Dacen Nagel and Coulson (1990) studied performance on maps of several complexities, which were produced by four different methods. They found that microcapsule maps were explored fastest and received the most favourable comments, followed by multi-textural and letter press plate maps. Thermoform maps yielded the slowest response times and unfavourable comments. Pike, Blades and Spencer (1992) investigated map reading performance of visually impaired children using microcapsule and thermoform maps. They found no significant differences in performance between map types. As Perkins (2002) points out, difficulties may arise when trying to compare different production methods in this way. Firstly, obtaining equal levels of complexity over pseudo-maps is very problematic. Secondly, in most production methods the symbols consist of the same material as the substrate, so it is not possible to vary substrate while keeping the symbols constant across substrates.

In the present study, the two potential problems mentioned above were avoided. Firstly, abstract symbol matrices were used, ensuring equal levels of complexity across trials. Secondly, the displays were constructed using a new technology, the TIMP tactile inkjet printer¹, can print tactile images in polymer onto a large variety of substrates. This technology therefore allowed us to compare a range of substrates, while keeping other factors constant.

The aim of this study was to determine what substrates or types of substrate are most suitable for the production of tactile maps and diagrams. The suitability of a substrate can be defined in two ways. Firstly, substrates may vary in ease of extraction of information. This variation may be caused by differences in contrast between the substrate and the symbols that are printed on it. As Keates (1982) suggested, visual detection of a symbol will depend on symbol size and the contrast with the background on which it appears. Likewise, tactile detection might depend on a similar relationship between symbol and substrate. Material properties like roughness and absorbency might also affect ease of information extraction by influencing the speed at which one can move the fingers. Numerous studies have explored the perception of roughness. For example, Lederman (1974, 1981, 1983; Lederman and Taylor 1972) found that groove width and finger force

¹ The TIMP machine uses a 500 nozzle, 180 dots per inch, piezo, drop on demand industrial printhead. Ultraviolet cured ink drops of 80 picolitres are built up in a multi-layer process. A detailed description of the printing process can be found in McCallum and Ungar (2003).
were the most important factors in the perception of roughness of gratings. In another study on roughness perception, Heller (1989) did not find differences in smoothness judgements between sighted and blind participants nor between passive and active touch. These studies suggest that observers are able to differentiate between materials over a range of roughness levels.

The second aspect of substrate suitability is related to the preferences of users. In a study by Ekman, Hosman and Lindström (1965), participants gave preference judgements on seven surface textures, ranging from paper to coarse sandpaper. Participants stroked pairs of surfaces and judged the "character of the surface in terms of … preference”. Ekman found that smoother textures were preferred over coarse ones. However, in a recent survey of tactile map users (Rowell & Ungar, 2003) in which participants were presented with identical maps (produced by inkjet printing as in the present study) on two different substrates, all participants who commented expressed a preference for the rough surface over the smooth one.

In this study, we attempted to determine which substrates allow easy extraction of information in terms of the relative time taken to identify symbols. We also aimed to investigate further the relationship between preference and roughness in the hope of clarifying previous findings.

Method

Participants

Twenty-nine sighted and visually impaired people took part in the study. Fifteen visually impaired participants (10 males and 5 females) were recruited at the Royal National College in Hereford, U.K.. Their ages ranged from 17 to 50, with a mean age of 29.8. Eight participants were totally blind and seven had some form of residual vision. One blind male (39 years) at Anglia Polytechnic University in Chelmsford also participated. Ten visually impaired participants were frequent Braille users. Fourteen sighted participants (4 males and 10 females) were recruited at the University of Surrey. They were aged between 17 and 49, with a mean age of 25.1 years.

Materials

On the basis of crossing seven types of substrate with seven different arrays of symbols, 49 experimental displays were constructed. The seven substrates used in this study were: rough plastic (high impact polystyrene with a rough finish), smooth plastic (high impact polystyrene with a smooth finish), rough paper (the reverse side of Avery Dennison SU5134), smooth paper (Avery Dennison SU5142), microcapsule paper (Zychem), textured PVC film (Braillon) and standard grade aluminium. Displays were printed using the TIMP tactile printer. All substrates were backed by a rigid sheet of MDF and were 29.7 x 21.2 cm (A4). Each array measured 25.8 x 19.2 cm and contained nine rows of eight symbols. Five shapes were used, which had been found to be highly discriminable (Rener, 1993): outline circle, ellipse, square, inverted T and inverted V. The T and V in Rener’s set were turned 180 degrees in order to prevent association with print letters. Four of the shapes were randomly distributed over nine rows of eight symbols. The fifth shape, an inverted V, was used as the target symbol. Eight targets were randomly distributed across the first eight rows. The ninth row contained zero, one or two target symbols in order to prevent counting. This row was disregarded in data collection. Symbols were 8 x 8 mm (except for the ellipse which was 5.5 x 11 mm), which is a size at which symbols have been shown to be readily identifiable and discriminable (Horsfall & Vanston, 1981). Line width was 1.3 mm and line height was nominally 340 µm. This height is in the middle to lower ranges of common heights for tactile and Braille features produced by other methods and is well above the thresholds of size and elevation for identification of tactile symbols (Jehoel, Ungar & Rowell, in preparation). Time and material input were minimised at this height, while readability was maintained. On the left side of the page, horizontal lines were printed that enabled participants to keep track of their position on the display.

Procedure

The experiment consisted of a tactile search task and a preference ranking task. Sighted participants and those with residual vision were blindfolded during both tasks. The search task was performed first. Participants were asked to scan the arrays of symbols as fast and as accurately as possible, proceeding from the top left corner to the bottom right corner and to give a verbal response when encountering a target symbol. Participants were asked to use their right hand to explore the rows of symbols. They used their left hand to keep track of their position by placing it on one of the horizontal lines to the left of each row. After a practise trial, 14 displays were presented in two sets of seven, each set containing all substrates and all arrays. The two sets were replications and did not differ in any meaningful way. The order of substrates and arrays was pseudo-random, making sure that participants explored each substrate twice with a different
array. A digital video camera was used to record the amount of time that was needed to complete the eight \times eight arrays and to record errors (false negatives and false positives).

![Figure 1](image)

**Figure 1** shows an example of the displays.

Upon completion of the search task, participants were asked to rank all substrates in order of preference. Participants received all seven substrates in a pile of random order and lined them up on a table in order of preference. The experimenters did not suggest any basis for ranking, instead participants were simply asked to decide on the basis of how much they liked each substrate. After the ranking task, participants were asked to explain the basis for their judgements.
Results

Errors

Overall, very few errors occurred in identification of the target symbol. A total of 464 target symbols (29 participants x 8 target symbols x 2 presentations of a substrate) was explored on each substrate. Table 1 shows the total number of errors. The number of errors was very small and there was no evidence of any relationship between substrate type and number of errors. Therefore, the errors were disregarded in further data analysis.

Table 1: Number of errors in identification of target symbol

<table>
<thead>
<tr>
<th>Substrate</th>
<th>False negatives</th>
<th>False positives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rough plastic</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Smooth plastic</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Rough paper</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Smooth paper</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Microcapsule paper</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Brailon</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Aluminium</td>
<td>15</td>
<td>0</td>
</tr>
</tbody>
</table>

Roughness

The data suggested that substrate roughness played an important role in both scanning speed and preference rankings. Average substrate roughness was measured with an interferometer. Figure 2 shows roughness values for each substrate and how these relate to scanning time, which will be discussed later.

Figure 2: Roughness and mean search times of substrates

Time

Search time was measured from the moment participants touched the first symbol in the display until they left the last symbol in the eighth row (M = 77.6s, SD = 33.5s). Visually impaired participants performed the task faster than sighted people (M_{VI} = 56.8s, SD = 23.2s and M_{sighted} = 99.8s, SD = 28.0s). The standard deviation in mean search time between participants was quite large. However, the standard deviation within participants was considerably smaller (mean SD = 10.2s). This indicates that, although mean scores differed greatly between participants, all participants scored within certain limits from their own mean. In order to be

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2 Measurements were taken using Wyko RS-2 Interferometric Surface Profilometer. An interferometer is able to generate detailed topographical information by scanning an optical beam over a material and analysing the interference of reflected fringes. The unit used in this experiment had a lateral resolution of 1 micron and depth resolution of 5 nanometres.
able to compare the means of all participants therefore, each participant's scores were standardised by conversion to z-scores. Table 2 shows the mean z-scores for all substrates.

Table 2: Mean Z-scores (and standard deviations) of search time by visual status and preference group (see Preferences subsection for details)

<table>
<thead>
<tr>
<th>Substrate</th>
<th>VI</th>
<th>Sighted</th>
<th>Rough</th>
<th>Smooth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rough paper</td>
<td>-0.38 (0.42)</td>
<td>-0.37 (0.66)</td>
<td>-0.37 (0.58)</td>
<td>-0.46 (0.48)</td>
</tr>
<tr>
<td>Microcapsule</td>
<td>-0.33 (0.32)</td>
<td>-0.25 (0.43)</td>
<td>-0.37 (0.35)</td>
<td>-0.15 (0.40)</td>
</tr>
<tr>
<td>Smooth paper</td>
<td>-0.06 (0.54)</td>
<td>-0.15 (0.41)</td>
<td>-0.17 (0.46)</td>
<td>0.04 (0.53)</td>
</tr>
<tr>
<td>Braillon</td>
<td>0.02 (0.50)</td>
<td>-0.06 (0.38)</td>
<td>0.03 (0.47)</td>
<td>-0.15 (0.39)</td>
</tr>
<tr>
<td>Rough plastic</td>
<td>0.08 (0.69)</td>
<td>0.17 (0.64)</td>
<td>0.11 (0.65)</td>
<td>0.23 (0.72)</td>
</tr>
<tr>
<td>Smooth plastic</td>
<td>0.31 (0.54)</td>
<td>0.40 (0.42)</td>
<td>0.33 (0.45)</td>
<td>0.22 (0.47)</td>
</tr>
<tr>
<td>Aluminium</td>
<td>0.33 (0.45)</td>
<td>0.24 (0.46)</td>
<td>0.43 (0.38)</td>
<td>0.28 (0.62)</td>
</tr>
</tbody>
</table>

A mixed measures analysis of variance with visual status (visually impaired versus sighted participants) as a between subjects factor and substrate as a within subjects factor, showed that the type of substrate had an overall effect on search time ($F(6, 162) = 8.03; p < 0.01$). The main effect of visual status ($F(1, 27) = 0.00; p = 0.99$) and the interaction effect ($F(6, 162) = 0.19; p = 0.98$) were not significant. Since there were no time differences between the two participant groups, their data were collapsed for further analysis.

Pair-wise comparisons indicated which substrates differed significantly in search time ($p < 0.05$). Aluminium and smooth plastic were scanned more slowly than Braillon, smooth paper, rough paper and microcapsule. Participants required more time scanning rough plastic than rough paper and microcapsule paper. Search time for Braillon was longer than that for rough paper and microcapsule. Figure 3 represents these differences diagrammatically, with connecting lines indicating significant differences in search time between substrates.

Figure 3: Significant differences in search time indicated by connecting lines

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3 Z-scores indicate the number of standard deviations of each time measurement from the participant’s own mean score.
Preferences

Participants’ preferences for substrates, as indicated by their responses to a specific question about the basis of their preference rankings, showed two distinct patterns. The majority (9 visually impaired and 10 sighted participants) indicated that they preferred rougher substrates over smoother substrates (see Figure 2 for roughness values of the substrates). A minority (5 visually impaired and 4 sighted participants) preferred smooth substrates over rough ones. On this basis, it was therefore possible to assign participants to one of two preference groups: rough and smooth.

Figure 4: Mean ranking scores for preference groups

Participants ranked all substrates on a seven-point scale, assigning more points to highly preferable substrates. Figure 4 shows the mean ranking scores of the two preference groups. The data suggest that there is an interaction between type of substrate and preference group. Multiple Wilcoxon signed rank tests, were used to explore differences in preference between substrates. There were no significant differences in preference for substrate among the smooth preference group. For the rough preference group, aluminium and smooth plastic were ranked significantly lower than rough paper, microcapsule paper and Braillon. Rough plastic was ranked lower than rough paper and microcapsule paper. In order to examine differences in preference between the preference groups, multiple Wilcoxon tests were performed. The rough preference group gave a significantly higher ranking than the smooth preference group to microcapsule paper, rough paper and Brailleon, and gave a significantly lower ranking to aluminium.

Time and preference

There was a significant correlation between the z-scores of search time and the preference ranking scores ($r = -0.16, p < 0.05$). Table 2 shows the z-scores for the two preference groups. A two-way repeated measure ANOVA, using preference groups as a factor, was conducted to investigate differences in exploration time for the two preference groups. There was a main effect of substrate type ($F(6, 156) = 7.15; p < 0.01$). However, there was no main effect of preference group on exploration time ($F(1, 26) = 0.001; p = 0.97$) and no interaction between preference group and type of substrate ($F(6, 156) = 0.69; p = 0.66$).

Discussion and Conclusions

In this study, blind and sighted participants performed a search task on seven different substrates. Search time was measured and participants ranked the substrates on the basis of their individual preferences. In general, paper substrates were explored faster than plastic and aluminium substrates. This might be related to surface characteristics such as roughness and absorbency. The plastic and aluminium substrates were smoother and less absorbent, possibly causing the fingers to stick to the substrate and slowing down

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4 One participant did not show a clear preference pattern and was disregarded in the analysis of preference data.

5 Bonferroni correction for multiple comparisons set the significance level for these tests to $p < 0.0024$.

6 Bonferroni correction for multiple comparisons set the significance level for these tests to $p < 0.007$. 
exploration. Most participants did not only explore paper substrates faster, they also preferred them over plastic and aluminium substrates. When asked about the reasons for their preferences, most participants (18 out of 29) reported that they either 1) liked paper and rough substrates because it was easier to move their fingers across these rougher substrates, or 2) disliked the plastic and aluminium substrates because of their stickiness, which irritated their fingertips and made it more difficult to move across the display. Interestingly, a small number of participants (8 out of 29) preferred the plastic and aluminium substrates because of their smoothness, which reportedly made it easier to move their fingers across. Observations suggested that these participants had dry skin and/or used light touch, which might make it easier to run their fingers across a smooth surface than a rough one. However, the data on exploration time suggest that, regardless of preference, participants explored plastic and aluminium substrates more slowly than paper ones.

The data suggest a U shaped relationship between surface roughness on the one hand and preferences and search time on the other (see Figure 2). Very smooth substrates such as shiny plastic and aluminium are explored more slowly and are less preferred than fairly smooth substrates such as rough plastic and smooth paper. Rough paper and microcapsule paper, which are rougher, are most preferred and fastest explored. Braille, which is the roughest substrate used in this experiment, had an intermediate score on exploration time and preference. The U shaped relationship may also explain the apparent inconsistency between the findings of Rowell and Ungar (2003) and of Ekman and colleagues (1965). As the textures used in the latter study were considerably rougher than those used in our studies, they were possibly in the range of roughness where preference begins to decrease. Another explanation for the inconsistency relates to the purpose of the task. Both in the present study and in the study by Rowell and Ungar, the main task involved scanning an image on the substrate. In Ekman's study, however, the task focussed on the bare substrate itself.

Given the U shaped relationship between surface roughness and performance, it is unlikely that our data can be explained in terms of difference in roughness between the substrate material and the and the surface of the symbols (which was of constant roughness and relatively smooth). Previous research (Lederman, 1974; 1981) suggests that discrimination of roughness increases as difference in roughness increases. If increasing difference in roughness between symbol and substrate were the main factor facilitating identification of the symbols, performance would be expected to improve as substrate roughness increased. The fact that it did not implies that difference in roughness can at best be only one of a number of factors determining differences in performance across substrates.

The results of this study suggest that paper substrates, in particular rough paper and microcapsule paper, would be most suitable for the production of tactile maps and diagrams when using an inkjet printing method. These results are based on exploration time and user preferences. However, other factors should be considered as well. First of all, the selection of a substrate depends on the functions of the map or diagram. For example, durable substrates such as plastic and aluminium are more suitable for use in public places (e.g. a map on the wall of a train station), whereas paper substrates, which are lightweight and can be folded up, can more easily be taken with the individual user. Production cost is another factor in the selection of substrates; paper substrates are usually cheaper than plastics and aluminium. Another consideration is the use of maps and diagrams by visually impaired people with residual vision. The use of residual vision is often hindered by reflection and matt substrates, which have less reflection, may be more suitable in this respect.

It could be argued that the specific task used in the present study lacks ecological validity, and that the results may not generalise to the use of actual tactile maps and diagrams in complex, real-world tasks. However, it seems likely that the relative properties of substrates would have an even greater effect in the context of many map or diagram tasks, in that the reader is likely to spend a greater amount of time with their finger in contact with the background material while scanning the display for information. The relative advantages of moderately rough substrates are therefore likely to hold for most tactile display tasks as for our search task.

This study suggests that surface roughness has an effect on the exploration of and preference for substrates. However, other surface characteristics might also have an effect. Firstly, absorbency of the material will influence the amount of sweat that remains on the finger and, therefore, stickiness of the surface. A second characteristic is thermal conductivity, which influences the subjective feeling of temperature. In this study, a large number of participants spontaneously remarked that the aluminium substrate, which has high thermal conductivity, felt cold. Surface softness is considered a robust perceptual dimension of texture (Hollins, Feldowski, Rao, & Young, 1993). Another characteristic found in perception studies is elasticity or springiness (Srinivasan & LaMotte, 1995). Friction, surface chemistry such as acidity and surface energy might influence exploration and preferences as well. More detailed research could indicate what surface characteristics influence the ease of extraction of information and the preferences for substrates.
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References


