TITLE: Comparing graphical pattern matching on tablets and phones: Large screens are not necessarily better

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Abstract

Significance: Touchscreen-based, multimodal graphics represent an area of increasing research in digital access for individuals with blindness or visual impairments; yet, little empirical research exists on the effects of screen size on graphical exploration. This work probes if and when more screen area is necessary in supporting a pattern matching task.

Purpose: Larger touchscreens are thought to have distinct benefit over smaller touchscreens for the amount of space available to convey graphical information non-visually. The current study investigates 2 questions: 1) Does screen size and grid density impact a user's accuracy on pattern matching tasks? 2) Does screen size and grid density impact a user's time on task?

Methods: 14 blind and visually impaired individuals were given a simple pattern matching task to complete on either a 10.5" tablet or a 5" phone. The patterns were made up of 5 vibrating targets imposed on sonified grids which varied in density (higher density = more grid squares). At test, participants compared the digital pattern on the touchscreen to a group of physical, embossed patterns and selected the matching pattern. Participants were evaluated on time spent exploring the pattern on the device and their pattern matching accuracy.

Results: Tablet-sized touchscreens afforded significantly better pattern identification accuracy, but participants were significantly slower to identify tablet patterns than phone patterns. Low grid densities also showed poorer accuracy overall.

Conclusion: A tradeoff exists between devices that seems to be task-dependent. Users may find a tablet most useful in situations where the accuracy of graphic interpretation is important and is not limited by time. Phones may be most useful in opposite scenarios, which prioritize temporal efficiency and only garner the gist of the graphic.

I. Introduction

Touchscreen-based devices, such as smartphones and tablets, are changing the way that users access and manipulate information. Recent research has demonstrated that the inclusion of multimodal information and universal design in the native interface of this technology make it especially beneficial as an information-access device for people who are blind or visually impaired (BVI).[1-4]

While text-to-speech software, via Apple's VoiceOver and Google's TalkBack, is widely available for making textual information accessible in the digital world, there remains no comparable access solution for digital graphical material. This lack of access to graphical content represents a large challenge to BVI individuals as it directly affects their educational, vocational, and social progress as well as individual independence.[5,6] Access to graphics is currently limited to verbalized textual descriptions of images, sonification-based graphics, refreshable pin arrays, and force-feedback devices.[3,7] These devices and rendering solutions are often expensive, lack portability, or are not fully multimodal, contributing to infrequent usage and limited adoption by BVI people. A more recent approach to accessible graphics focuses on using the vibration, audio, and visual displays built within commercially available touchscreen smart-devices, which are relatively inexpensive, portable, and already adopted within the BVI community. Recent studies have illustrated the potential of conveying myriad graphics on touchscreens, including simple stimuli from lines and points to more complicated shapes, graphs, and maps.[1,2,4,8] However, most of these investigations and recent new touchscreen-based solutions (e.g., See ColOR, Feelif, and ViTAL)[9-11] rely on the use of larger screens, such as tablets, despite the significant prevalence and preference of smaller, hand-held mobile devices being used by BVI people for everyday tasks.[12,13]

This study addresses the anecdotal belief that larger touchscreens offer distinct benefits for graphical exploration to users over smaller screens, and thus may equate to better user experience and performance. However, there is a distinct lack of empirical research regarding the assumption that larger screens are a better medium for supporting graphical exploration. This study aims to provide empirical evidence regarding the trade-off between performance and device size to better understand whether screen real estate is indeed a key factor in the interpretation and navigation of multisensory content, especially graphical concepts, on touchscreens. Specifically, we seek to understand if and how target identification and pattern matching performance, two relatively simple tasks in the graphical domain, compare across two devices with different screen sizes — a tablet and a phone.

Matching nonvisual grid-based target patterns was chosen as it is a fundamental graphical task that requires little prior knowledge of graphical information, unlike more complex tasks such as shape identification and graph interpretation. Using targets avoids the semantic retrieval failure associated with trying to name discrete shapes,[14,15] enabling us to focus specifically on task performance. Second, we are interested in the impact of screen size on perception and retention of important stimuli for which the pattern matching task is well-suited. Our interest is not in the recognition of shapes or 2D objects nor the interpretation of complex spatial entities such as graphs or charts, which involve extra processes such as integrating features (e.g. size and surface) to determine distinct objects.[15] Finally, grids benefit this specific task because they discretize the screen area, dividing it into smaller, functional entities that can be evaluated on a continuous scale. Performance on the target identification and pattern matching tasks in this work will provide insight on when and where the use of tablets is actually necessary over more commonly accepted and prevalent smaller mobile platforms.

A. Research Questions

To investigate the role of screen size in conveying simple graphics using vibratory feedback on a touchscreen, we pose two research questions:

1. Does screen size and grid density impact a user’s accuracy on pattern matching tasks?
2. Does screen size and grid density impact a user’s time on task?

Grid density refers to the number of grid squares that are presented on the screen, with a higher number of squares representing high grid density and a lower number of squares representing low grid density (see Figure 1).

II. Methods and Procedures

A. Demographics

Fourteen individuals (19-74 years; M = 42 years) with blindness or visual impairment were recruited (with permission) at the 2017 National Federation of the Blind Conference (see Table 1). Of the 14 participants, a majority were female (57%). To participate, individuals were required to use some form of access technology (e.g. braille or screen readers). The range of diagnoses of the participants are listed in Table 1. All individuals gave informed consent and received a $25 gift card for participation. This study was approved by the Saint Louis University Institutional Review Board.

[Table 1]

B. Materials

1) Demographics Questionnaire: Participants were administered a short demographics questionnaire at the beginning of the study. This questionnaire collected participant age, gender, visual impairment, onset of impairment, as well as any touchscreen/computer aids used (see Table 1).

2) Tablet and Phone: The tablet and phone chosen for this study have a 2:1 ratio in both resolution and physical size, providing a straightforward comparison of screen size. A 10.5" Samsung Galaxy Tab S (288 pixels per inch resolution) with a 9" active area was used for the tablet condition. A 5" Samsung Galaxy S4 phone (441 pixels per inch resolution) with a 4.4" active area was used for the phone conditions. The devices were outfitted with rubber bands around the active screen area to create a physical boundary which prevented accidental pressing of ‘soft buttons’ on the screen.

3) Grid Layouts: Twelve grids were explored, with grids divided into 3 groups with 4 grids in each group. Regardless of device, grid groups consisted of: 1) 6 squares (2 x 3, Low Density); 2) 12 squares (3 x 4, Medium Density); and 3) 20 squares (4 x 5, High Density). Five grid squares contained targets (vibrating squares), and those targets occupied 40% of the space in the squares in which they appeared. Forty percent occupancy of targets was determined to be a reasonable ratio of stimuli versus no feedback for promoting target identification while not overstimulating the user. Five targets allowed for pattern flexibility across all grid sizes without having excessive empty space containing no feedback in low density grids. The same number of targets (5) was kept constant across grid groups for consistency in the complexity of the pattern matching task.

The target vibration pattern (SHORT_BUZZ_100) was chosen from Immersion's UHL Library for the strength of its signal and the regularity of its vibrational pattern.[16] Grid lines played an auditory tone when touched by the participant's finger. Targets vibrated when a participant's finger ran across them. Grid lines played an auditory tone from Android's native tone library (DTMF_A for horizontal gridlines; DTMF_D for vertical gridlines) when touched by the participant's finger. Two tones were chosen to convey the horizontal and vertical grid lines to reduce the chance of the participant of confusing one gridline from another. All grid lines were rendered as approximately 4 mm thick on both devices, which was determined from pilot studies to be sufficient feedback for determining the presence of a grid line. An example of a grid from each of the 3 groups can be found in Figure 1. Corresponding tactile embossed versions of these digital grids were prepared using a Viewplus Emprint Embosser for the Pattern Matching Task. Embossed versions were as close to the same size as the device screen as the embosser would allow, while still retaining the embossed integrity of the grid features.

[Fig. 1]

4) Pattern Matching Task: A program to display the grids in a random order per grid group was created to run on Android 5.0. This program allowed participants to explore the

digital grid at their own pace until they self-reported that they could identify a physical, tactually embossed printout of the graphic among 4 alternative options. In this task, participants were asked to choose the tactile grid that matched the pattern they had just felt without access to the digital pattern on the touchscreen. Of the 4 alternatives in the multiple choice embossed assessment, only one image was the correct grid. This task is further described in the context of the study in Section II-C.

C. Procedure

A repeated measures between-subjects design was employed. Participants were assigned to a device group upon arrival according to their participant number (odd numbers received only the tablet, even numbers received only the phone). Each session took approximately one hour to complete. After obtaining consent, a demographic questionnaire was completed by verbally asking participants for general information about themselves, including their age, gender, and information regarding their visual impairment(s) and familiarity with tactile images. After this short intake session, participants were introduced to either a phone or a tablet for use during the study.

Participants began with a short training period before administering each group of experimental trials with the three grids. During training, the physical device was described and participants practiced with an exemplar grid. These grids were not subsequently used during the study. During practice, participants were able to ask questions of the experimenter and were given corrective feedback about their responses. All questions were answered before commencing with the experimental trials. Participants were told that targets vibrated and that the grid lines played different sounds depending on if they were horizontal or vertical grid lines.

During the experimental trials, participants were asked to explore a pattern. For each grid, they were told the size of the grid (e.g. 2 x 3) and were reminded of the number of targets to find (5). Participants were instructed to finish exploring each digital grid as quickly as possible, but no time limit was imposed. Their goal was to find all of the vibrating targets on the touchscreen and after exploration, to match the pattern formed by the 5-target configuration with an embossed hardcopy analog chosen from four possible alternatives (as described above in Section II-B.3.

Participants explored 12 grids in total, comprising 4 grids per each of the 3 grid-size groups. Each grid group was presented in the same order, with large (low density) grids (6 squares) presented first, medium density grids (12 squares) presented second, and small (high density) grids (20 squares) presented last. This fixed order was imposed to convey a progression of difficulty to the participant as they explored less condensed to more condensed grid sizes. Due to this design, a learning effect may have occurred and is taken into account in the interpretation of analyses in Section III.

III. Results

Data collected in this study included time to explore the three digital grids across the two sizes of touchscreens (phone vs. tablet) as well as matching accuracy on the multiple-choice Pattern Matching Test. Analyses were conducted using IBM SPSS Statistics 2015.
To determine if the larger screen size of the tablet is advantageous (e.g. faster and more accurate than the phone), performance during the study was examined in two ways: 1) time participants spent identifying a digital grid on a touchscreen device, and 2) the correct identification of the pattern on the grid given a choice of 4 embossed versions (see Figure 1).

A. Pattern Identification

A two-way ANOVA was performed to examine the effects of the interaction between touchscreen device and grid size as a function of pattern identification accuracy. No statistically significant interaction was found between the means, implying no difference in pattern identification accuracy between the tablet and the phone regardless of grid density ($F(2,18) = 3.441$, $p = .054$, *partial* $\eta^2 = .277$) (see Table 2). We note that this is a single study of relatively small sample and effect size, but this is an interesting overall finding, suggesting that pattern identification accuracy did not improve in the grid sizes tested with the larger screen size.

[Table 2.]

Although we found no significant interaction effects for identification accuracy between the screen size and grid density, the accuracy data presented in Table 2 convey a difference in pattern identification performance across the different devices. To investigate this observation, an independent samples t-test was performed comparing pattern identification accuracy with device. A statistically significant difference was found between the mean accuracy for the tablet (M = 90.17, SD = 15.64) vs. the phone (M = 76.33, SD = 12.59) ($t(22) = 2.386$, $p = .026$, 95% CI = 1.81 – 25.85). In short, patterns displayed on the tablet tended to be identified correctly more often than phone patterns, irrespective of grid density.

Pattern identification accuracy is plotted in Figures 2 and 3 to better examine the trend of the data. As can be seen in Figure 2, average accuracy on the tablet increased as grid density increases. This suggests that the tablet's additional screen real estate may become more valuable as the information being displayed becomes denser. However, contrary to this finding, mean pattern identification accuracy on the phone was relatively consistent across grid sizes, but fared the worst on the highest density grid (Figure 3). This suggests that there likely is a limit to the density of information that can be accurately portrayed using the smaller screen real estate. It is noteworthy, however, that even for the small, high density grids used in this study, users were still able to achieve around 70% accuracy in correct pattern identification with the phone.

The positive trend found for the tablet pattern identification accuracy across grid densities may also represent an indication of a learning effect occurring across trials. However, looking at the data presented in Figure 2, the majority of the grids were 100% identified, with only 3 low density grids (#0-2) and 1 medium density grid (#1) having less than 100% accuracy identification rates. Further, we do not observe a similar upward trending phenomenon in the accuracy of pattern identification performance with the phone, which would support a learning effect among users. Thus, we argue that this upward trend is indicative of better performance rather than a learning effect. This is further supported by the hypothesis that less “white” space on a tablet (space with no feedback) is better than too much white space, which may often cause the user to get lost on the screen. It might be that the higher density grid investigated in this work embodies a near optimal ratio of density versus white space on the tablet screen.

A one-way ANOVA was also performed to examine the effect of grid density with identification accuracy to determine if there was a significant difference between the accuracy means of grid density collapsing across the two devices. No significant difference was found ($F(2,21) = 1.832$, $p = .185$), implying no difference in pattern identification as a function of grid density (Low density: $M = 75.37$, $SD = 13.30$, 95% CI = 64.26 – 86.49; Medium density: $M = 89.50$, $SD = 12.49$, 95% CI = 79.06 - 99.94; High density: $M = 84.88$, $SD = 18.61$, 95% CI = 69.31 - 100.44). Despite the overall trend of the data, no single grid density led to better performance compared to the others. This implies that users of tablets and phones achieved comparable accuracy performance despite changes in information density.

[Fig. 2]

[Fig. 3]

B. Grid Exploration Time

We were also interested in comparing exploration time between the two devices and three grid densities. For the average exploration time per participant, see Figure 4.

A two-way ANOVA was performed to examine the effect of the interaction between touchscreen device and grid density with the time it took to identify a grid pattern. There was no statistically significant difference found between the means, implying no difference in pattern exploration time between the tablet and the phone regardless of grid size ($F(2,18) = 1.775$, $p = .198$, *partial* $\eta^2 = .165$) (see Table 2). In other words, grid exploration did not take significantly longer on one device than the other no matter the density of the grid explored.

However, statistically significant results were found between grid density and pattern identification times ($F(2, 18) = 23.633$, $p < .001$, *partial* $\eta^2 = .797$) and between device and pattern identification times ($F(1,18) = 20.015$, $p < .001$, *partial* $\eta^2 = .527$). These results indicate that individuals spent significantly less time trying to explore and identify patterns on low density grids on the touchscreen than medium and high density grids. Individuals also spent significantly less time exploring patterns on phone grids than tablet grids. This was somewhat expected given the smaller screen real estate on the phone.

To further investigate the time discrepancy between identifying phone and tablet grids, an independent samples t-test was performed to examine the effect of touchscreen device with pattern identification time to determine if there was a significant difference between the identification times of the 2 devices. A statistically significant difference was found between the means of the tablet ($M = 125.9$, $SD = 63.575$) and phone ($M = 72.8$, $SD = 35.575$) pattern identification time ($t(22) = 2.530$, $p = .019$, 95% CI = 9.583 – 96.813). These results show that phone-based grids do, indeed, tend to be identified quicker than tablet-based grids.

[Fig. 4]

IV. Discussion of Results

This study sought to investigate how screen size affects information extraction and pattern matching and the ability to identify digital patterns of information in varying sized (different information density) multimodal grids rendered on touchscreen-based smart devices. Our findings illustrate that participants were able to match the digital grid with the correct embossed grid with an average score of 86% overall across devices. When examining the performance on the tablet vs. the phone, tablet users were found to be significantly more accurate than phone users in identifying digital patterns. Namely, tablet pattern identification accuracy ranged between 75-100% across all grid densities (see Table 2), with the highest performance identification accuracy occurring on the high density grids. This aligns with the hypothesis that the true value of larger screen real estate likely manifests most with higher density stimuli.

Performance data with the phone, while worse than with tablets, is not unfavorable, with pattern identification accuracy ranging from 70%-83% (see Table 1). Depending on the context of the task, such rates may still be acceptable, as they are quite high overall. Phone users' pattern identification performance was particularly affected by the high density grid, where accuracy was the lowest. This is likely due to the limited space for rendering these condensed grids (4x5; 20 squares). The highest pattern identification accuracy was observed on the medium density grids, perhaps indicating that, for phone interfaces, there is an ideal ratio of information density to white space that is around 70% white space.

It was expected a priori that participants would perform the worst on the phone with the high density grid, as the grid squares were only about the size of the average adult finger pad. However, participants were still able to correctly identify the 20-square grid pattern almost 70% of the time, which suggests that it was still a very feasible task. It also suggests that this level of information granularity and information density is still usable on the touchscreen at smaller screen sizes. This result is promising, given that phone platforms are more commonly used than tablet platforms and are likely preferred for supporting every-day tasks.

It is worth noting however, that the exploration time at the high density grid for both tablet and phone users was the highest of the 3 grids. Participants spent about 2-3 minutes identifying the digital pattern. For the tablet case, this may simply be due to the distance participants had to travel and conceptualize while trying to find all 5 targets and understand the pattern. The phone is, however, about half the size of the tablet, affording faster exploration at the cost of a slight decrease in matching scores from those on the tablet. It is interesting to note that while the exploration time did not seem to improve performance for phone users on the high density grid (69.75% correctly identified), it was beneficial to tablet-users on the high density grid (100% correctly identified). The best time-correctness trade-off for phone users was the medium density grid, as users were able to correctly match 83% of grids with about a minute and a half average exploration time.

For the tablet users, the low density grids were not as effective for conveying patterns as the other two grid densities. Again, this finding seems to indicate that more screen real estate isn't always better, and may be problematic, when the grids are not as condensed. Although better performance on the high density grids may be due to a learning effect, we hypothesize that this could also be a reflection of where larger screen real estate is beneficial. This is also supported by the low grid densities yielding poorer performance, which we hypothesize is due to the less frequent feedback received between targets, causing users to be "lost in touchscreen white space" and leading to confusion in navigation of the graphic. Therefore, large screens may not be as beneficial for exploring simple graphics on a touchscreen due to the more frequent lack of feedback from the whitespace on the tablets screen.

In sum, our findings suggest that both large and small touchscreen devices have benefits and drawbacks that are highlighted by this study. The most telling finding is that tablet users tend to more accurately identify information while phone users tend to be quicker to gather information. Among everyday use, there seems to be a tradeoff of time and accuracy between device sizes that is task dependent. If the task is to explore a simple graphic, such as a pattern, as quickly as possible to get a sense of the overall information being presented without being overly concerned with accuracy in identification, phone-sized screens appear advantageous over a tablet given the shorter exploration time and comparable grid identification accuracy observed here. However, if the task is to identify the graphic as correctly as possible without a time limit, then the tablet may be beneficial as it affords the user with the maximum amount of space, which is particularly important as graphics become more condensed.

V. Conclusion

This study extends the current state of research on multimodal touchscreen interfaces by providing data-driven insights on whether or not large screen sizes are necessary for successful interpretation of graphical information. We present empirical results from a pattern matching task conducted across multiple information-density grids on both a tablet and a mobile phone, representing approximately 2/1 screen real estate difference, suggesting that tablet accuracy is significantly better than phone accuracy, but that phone exploration time is significantly faster than tablet exploration time. We discuss both advantages and limitations of each platform in the context of our study to inform future work in this area, which to date, has largely focused on tablets although the target demographic preferentially uses phones. This research probes the impact of screen real-estate on multimodal information transfer and helps to inform future work in the display of accessible graphics serving blind and visually impaired individuals, and mobile phone users at large.

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APPENDIX

TABLE 1. Participant Summary

#	Age	Sex	Impairment	Group
1	31	F	Retinopathy of Prematurity	Tablet
2	58	F	Glaucoma	Phone
3	23	F	Leber's Congenital Amaurosis	Tablet
4	19	M	Detached Retinas	Phone
5	59	M	Congenital Microphthalmia	Tablet
6	52	M	Glaucoma	Phone
7	41	M	Unknown	Tablet
8	29	F	Optic Nerve Hypoplasia	Phone
9	56	F	Retinopathy of Prematurity	Tablet
10	48	F	Optic Neuritis	Phone
11	49	M	Retinoblastoma	Tablet
12	25	F	Optic Nerve Atrophy	Phone
13	74	M	Leber's Congenital Amaurosis	Tablet
14	27	F	Pathological Myopia	Phone

TABLE 2. Means, standard deviations, and CIs for pattern identification accuracy and exploration time.

Identification Accuracy

Density	N	M (%)	SD	95% CI	
Tablet	12	90.167	15.642	82.865	97.468
Low	4	74.750	18.373	62.103	87.396
Medium	4	95.750	8.500	83.103	108.396
High	4	100.0	0.0	87.353	112.646
Phone	12	76.333	12.593	69.032	83.635
Low	4	76.000	8.602	63.353	88.646
Medium	4	83.250	13.696	70.603	95.896

High	4	69.750	14.080	57.103	82.396
Exploration Time					
Density	N	M (s)	SD	95% CI	
Tablet	12	125.971	63.575	108.306	143.636
Low	4	55.285	17.369	24.688	85.882
Medium	4	143.411	50.223	112.814	174.008
High	4	179.217	33.887	148.621	209.814
Phone	12	72.773	35.575	55.108	90.438
Low	4	32.410	5.937	1.8131	63.006
Medium	4	83.004	25.986	52.408	113.601
High	4	102.905	20.185	72.308	133.502