Effects of Increasing Command Capacity of Spatial Memory Menus in Tablets

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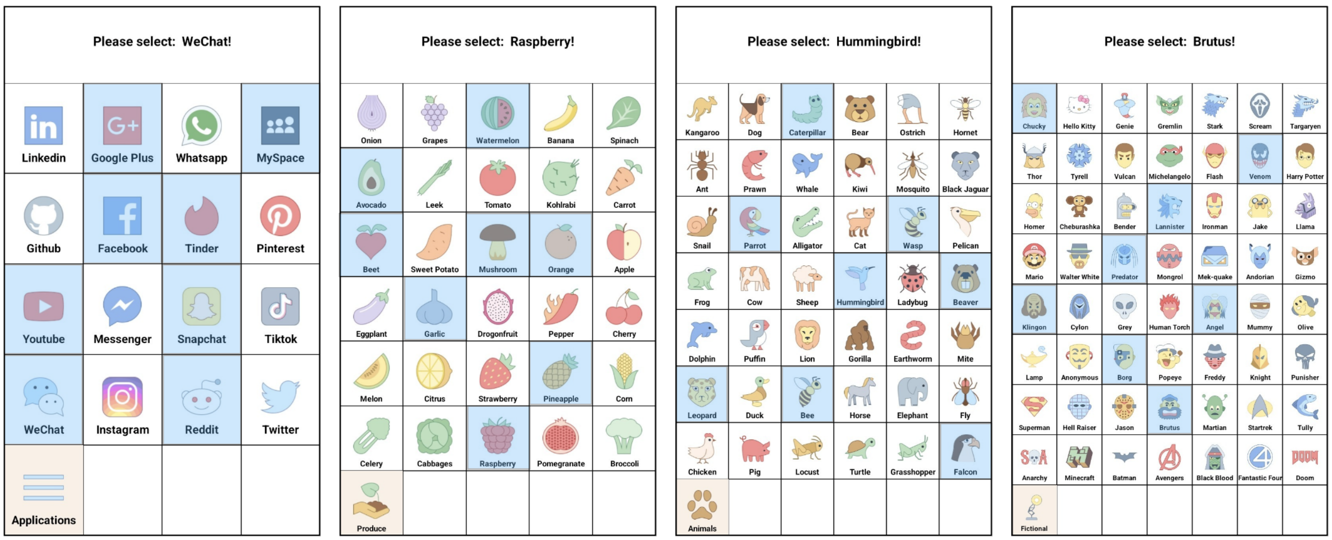

Figure 1: Interfaces used in the study with highlighted target locations. Image from left to right, Small (5x4), Medium (7x5), Large (8x6) and Extra-Large (9x7)

Abstract

Spatially-stable touch menus, like FastTap, leverage users' spatial memory to enable rapid command selection on tablets. Although these spatial tablet interfaces can aid in developing spatial memory of commands having a small command set, it is, however, unknown whether spatial memory remains beneficial when the number of commands grows. Therefore, we carried out a study to investigate spatial learning in four different sizes of single-tab FastTap Menus: Small, Medium, Large, and Extra-Large, with 16, 30, 42, and 56 items, respectively. Results indicated that people do develop spatial memory in all menus; however, there is a negative correlation between command capacity and spatial memory development in tablets. We contribute new knowledge on spatial memory development in touch tablets that can enhance the design of future spatial memory-based tablet interfaces.

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CCS Concepts

• **Human-centered computing → Empirical studies in HCI**.

Keywords

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1 Introduction

Spatial memory—the memory responsible for learning locations—can support the design of interfaces for rapid command selection [11]. When commands are presented in a spatially stable grid menu, spatial memory can aid in quickly learning command locations, enabling faster mastery of the menu. Research with smaller command sets suggests that spatial memory-based techniques can substantially outperform popular command-selection tools, such as Ribbon menus, hierarchical menus, or Marking Menus [6, 10]. However, it is unknown how increasing the command capacity of spatial interfaces affects the development of spatial memory.

The portability and ubiquitous nature of handheld devices, such as touch tablets, make them a well-suited platform to explore spatial interfaces [4, 6, 14]. Gutwin et al. [6] introduced a rapid command selection technique, FastTap Menu, on a 7-inch tablet. It uses a flat grid layout to display all available commands at once on the screen (see Figure. 1). They used a small 5x4 grid layout to display only 19 commands, with one cell reserved for a menu button. People can view the commands by pressing the menu button with their thumb and can select an item with their index finger while pressing the menu with their thumb. Once learned, users can quickly execute commands by combining menu invocation and command selection into a chunked thumb–index finger tap. Since it is common for modern handheld smart devices to have over 80 apps in their interfaces [12], it is important to know if the spatial memory interfaces will maintain their performance benefit when the menu size increases.

Gaur et al. [4], however, explored FastTap Menus with a relatively large command set consisting of 80 items. Another technique increased the command capacity of tablets by using proprioceptive knowledge of the user's hands [14], allowing menus to display 21 commands. Command capacity was further extended to 80 by multiplexing space between the thumb and index fingers. They focused on multiplexing spatial memory to accommodate many commands rather than the effect of increasing command capacity on spatial memory. Thus, the challenge remains to determine how varying command capacity affects spatial learning, especially on tablets. In this paper, we present a study to investigate how increasing the command capacity of spatial memory-based tablet interfaces affects the spatial learning of commands.

2 Study Interfaces

Since Gutwin et al.'s [6] FastTap Menus enabled rapid spatial learning on touch tablets and showed superior performance benefits compared to well-studied Marking Menus [6, 10], we selected FastTap as a representative of spatial memory-based touch interfaces for this work. To conduct the investigation, we developed four prototype FastTap Menus with different grid sizes: Small (5x4), Medium (7x5), Large (8x6), and Extra-Large (9x7) (see Figure. 1), where the bottom row was reserved for menu buttons. Therefore, our four menus had 16, 30, 42, and 56 items. Following the original design, we used the bottom left corner as the menu button, leaving the rest of the bottom row blank as we had only one tab in each condition.

Our study used an 8.7-inch tablet (Samsung Galaxy Tab A7 Lite). The four grid sizes were determined in light of prior studies [6], Parhi et al.'s [9] recommended size for touch targets (i.e., at least 9.6 mm), and through an iterative design approach. Additionally, we reduced the grid height (increased the height of the bar to approximately 1.7 inches at the top that displayed target questions) to about 7 inches, matching the original FastTap design.

Similar to the original FastTap [6], our study supported expert and novice selections. Commands remained hidden by default and could only be seen by pressing the menu button with a thumb. We kept a 200 ms delay between the menu press and commands appearing. Expert users could select a command, recalling its location from memory, without waiting to view the entire grid by pressing the menu button and target together (leveraging the 200 ms delay). This is known as an expert selection. Otherwise, users could wait to view the whole grid, visually search for the target, and then perform a selection, which is considered a novice selection.

3 Method

3.1 Tasks and Stimulus

The study consisted of a series of trials where a question appeared at the top of the grid. The user had to select the target with their index finger while pressing the menu activation button with their thumb, located in the bottom left grid corner. Upon a correct target selection, the grid cell's background turned green; otherwise, it was red for feedback. After a successful selection, the user had to remove their thumb from the menu to see the next question.

Eight targets were used as trials for each condition (see Figure. 1). During the study, trials were repeated (order randomized) over fifteen blocks. To make the study playful and test recall, we included a blind block after every fifth block, where the menu elements (i.e., icons) remained hidden even after pressing the menu button. So, there were, in total, eighteen blocks of trials, including three blind blocks.

3.2 Procedure and Study Design

We designed a within-subject study consisting of four conditions, namely Small (5x4), Medium (7x5), Large (8x6) and Extra-Large (9x7). Each condition contained eighteen blocks, including three blind blocks. Each block consisted of the same eight randomized trials, and the conditions' order was selected using a balanced Latin Square design [5]. Participants were instructed to complete tasks as quickly and accurately as possible.

Before starting the actual study, participants completed a practice session with a training interface consisting of a 4x3 grid (two targets over eighteen blocks) to learn the study tasks. Participants completed a NASA-TLX [7] questionnaire after each condition, and after completing all four conditions, they provided preferences and demographic information.

3.3 Participants and Apparatus

Sixteen individuals (9 Cis men, 6 Cis women, and 1 Trans man; 1 left-handed and 1 ambidextrous) between 19 and 32 years of age (mean 26.44) were recruited from a local university for this study. The study session lasted 60 minutes, and each participant received a $10 gift card. The experiment was conducted on a Samsung Galaxy Tab A7 Lite 8.7-inch multi-touch display. The application was developed for Android using Java.

4 Study: Results

We dropped 195 of 7680 (2.54%) trials from the regular blocks and 38 of 1536 (2.47%) from the blinds as outliers (3 s.d. away from the means of respective blocks) from our analyses. We report the effect size for significant ANOVA results as eta-squared: η^2 (considering .01 small, .06 medium, and >.14 large) and performed Bonferroni correction for post-hoc pairwise t-tests.

4.1 Trial Completion Time

The trial completion time was calculated from the target stimulus display to the user's successful selection of the required target.

Mean completion times are summarized in Fig. 2 for regular and blind blocks (B6, B12, and B18).

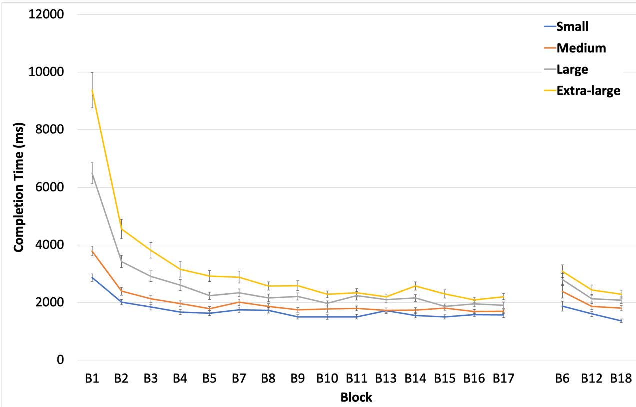

Figure 2: Trial Completion Time (±standard error) by Condition and Block.

For regular blocks, we found a significant effect of condition ($F_{3,45} = 54.11$, $p < 0.001$, $\eta^2 = 0.39$), with mean trial completion time the fastest at 1726.18 ms (s.d. 1003.94) for Small, 1992.76 ms (s.d. 1078.93) for Medium, 2570.33 ms (s.d. 1630.94) for Large, and the slowest at 3188.39 ms (s.d. 2210.50) for Extra-Large. Spatial learning occurred over time, so trial time significantly decreased across block ($F_{14,210} = 89.95$, $p < 0.001$, $\eta^2 = 0.63$). We also found a significant condition × block interaction ($F_{42,630} = 17.51$, $p < 0.001$, $\eta^2 = 0.39$). Post-hoc pairwise t-tests also showed significant (all $p < 0.001$) differences between all pairs, suggesting that increasing menu capacity could severely impact spatial learning.

For blind blocks, we observed a significant main effect of condition ($F_{3,45} = 8.38$, $p < 0.001$, $\eta^2 = 0.20$) and block ($F_{2,30} = 19.09$, $p < 0.001$, $\eta^2 = 0.13$), but no condition × block interaction ($F_{6,90} = 0.26$, $p = 0.95$). We found significant effects of condition and block (both $p < 0.001$), with Small being the fastest.

4.2 Rate of Expert Selection

We recorded the expert selections when a participant chose a target before it appeared in the menu (less than 200 ms), irrespective of accuracy. Interestingly, we did not find any effect of condition ($F_{3,45} = 0.28$, $p = 0.83$) or condition × block interaction ($F_{42,630} = 0.93$, $p = 0.59$), with Small (mean selection rate: 0.44, s.d. 0.52), Medium (0.43, s.d. 0.56), Large (0.44, s.d. 0.63), and Extra-Large (0.47, s.d. 0.71). Since the expert selection rate increased over time, we found a significant main effect of block ($F_{14,210} = 11.35$, $p < 0.001$, $\eta^2 = 0.23$).

4.3 Errors in Selection

The error count in each trial was calculated by the number of incorrect targets selected before the accurate one. For regular blocks, we found a significant effect of conditions ($F_{3,45} = 7.20$, $p < 0.001$, $\eta^2 = 0.06$), with Small being the most accurate (mean: 0.05, s.d. 0.24), Medium (mean: 0.09, s.d. 0.33), Large (mean: 0.12, s.d. 0.41), and Extra-Large having the highest errors (mean: 0.16, s.d. 0.53) – indicating the negative effect of increasing menu size on spatial memory. Post hoc tests showed significant differences between all conditions (all $p < 0.01$) except for Medium and Large ($p = 0.05$). However, we did not find any effect of block ($F_{14,210} = 1.57$, $p = 0.09$) or condition × block interaction ($F_{42,630} = 0.79$, $p = 0.83$).

The blind blocks showed a significant difference for condition ($F_{3,45} = 7.18$, $p < 0.001$, $\eta^2 = 0.16$) and block ($F_{2,30} = 18.04$, $p < 0.001$, $\eta^2 = 0.16$), with mean errors for Small, Medium, Large, and Extra-Large being 0.18 (s.d. 0.74), 0.36 (s.d. 1.24), 0.59 (s.d. 1.56), and 0.86 (s.d. 2.10), respectively. However, there was no condition × block interaction ($F_{6,90} = 1.68$, $p = 0.13$). Post hoc tests showed significant differences between the pairs of Small:Large, Small:Extra-Large, and Medium:Extra-Large (all $p < 0.13$).

4.4 Subjective Responses

NASA-TLX responses were analyzed. Friedman tests showed a significant difference among all conditions, with the overall Extra-Large condition receiving the highest workload scores compared to others in all measures, while Small was perceived as requiring lower demand than Large and Extra-Large for mental, physical, and temporal measures (all $p < 0.89$). Among the four conditions, over 81% (at least 13) of participants preferred relatively smaller conditions (Small and Medium; Small being the most preferred) in all measures compared to Large and Extra-Large.

5 Discussions

5.1 All Menus Enabled Spatial Learning

Mean trial completion time decreased over the blocks (Figure. 2) in our four menus. All participants were new to these menus, so they spent a substantially longer time visually searching for the targets in the menus. At this stage, they were in the cognitive stage of spatial learning [3]. Research suggests that spatial memory develops as a by-product of interacting with objects [2] and is more effective with effort [1]. It could be possible that participants in our studies transitioned to the associative stage of spatial learning [3] after interacting with the menu for a short time. During the early stages of our study (around 3-5 blocks), we observed a significant decrease in trial completion time (as shown in Figure. 2). Participants began using more advanced selection methods by relying on their memory to recall target locations within the menus, instead of waiting for icons to appear on the screen (200 ms delay). In our study, participants developed spatial memory of commands across all menu sizes. They were more efficient in using their spatial knowledge in smaller menus than in larger ones.

5.2 Why Did Larger Menus Impede Spatial Memory Development?

We noticed that the rate of spatial development was significantly slower in larger menus. We see two potential reasons for these results. First, the relatively slower selection performances in larger interfaces can be described by the choice-reaction time of Hick-Hyman Law [8]. As the number of targets increased in larger menus—from 16 to 30, 42, and 56 items—the available choices for a user to select from increased substantially. Therefore, people might have spent more time searching for the target locations instead of selecting them. Despite FastTap allowing rapid command selection using spatial memory, a large number of choices could have hindered people from developing spatial memory quickly.

Second, people usually rely on landmarks present in graphical menus [15] to learn the location of commands. The grid lines of the FastTap menu, the bezels of the tablet device, and the corners can work as landmarks and support spatial learning, at least in smaller conditions. However, when the number of items increased, those existing landmarks might have weakened, as one landmark acted as a reference point for multiple items. Using additional landmarks [13] could be a way to improve spatial learning in larger-size menus, which can be a future avenue of research.

6 Conclusions and Future Work

In this paper, we examined the learning ability of users with FastTap Menus in four different sizes: Small, Medium, Large, and Extra-Large, containing 16, 30, 42, and 56 items, respectively. Although the rate of developing spatial memory became significantly slower as the menu size increased, our results indicated that people developed spatial memory in all menu sizes. We noticed that as the grid size increased, the time it took to make a selection and the number of errors also increased. Despite this, participants could still make expert selections regardless of menu sizes. Our research indicates a negative relationship between command capacity and spatial learning. Additionally, participants preferred smaller interfaces over larger ones as they felt study tasks became mentally and physically demanding when menu sizes grew.

Our research has made several contributions. First, to the best of our knowledge, this work is the first to explore the effects of increasing command capacity of spatial interfaces on the development of spatial memory in touch tablets. Second, we provide new empirical evidence that people do develop spatial memory regardless of the size of the command set. However, we observed that the development of spatial memory slows down significantly when the number of commands in interfaces increases. These findings could serve as a foundation for informing the development of future touch tablet interfaces that rely on spatial memory.

Our research has yielded promising initial results. Moving forward, we aim to explore multiple avenues. First, we limited our study to a single-tab FastTap menu, where multiple tabs can be used to multiplex spatial memory. We aim to expand our work to explore the effects of command capacity increase in multi-tab menus in future. Second, in this study, we only considered a simulated application in a controlled lab environment. We plan to develop real-world applications and invite participants to test them for a few weeks so we can gather performance data. Third, another area of the future plan is to implement the FastTap Menu in various screen sizes to study its performance. We are also interested in integrating this technology in new touch foldable phones, such as the Galaxy Z Fold 5, OnePlus Open, or Google Pixel Fold, to understand its performance and how it can improve the capabilities of these devices. Finally, we invite members of the ISS community interested in spatial memory interfaces and interaction design to come and discuss this fascinating research topic with us and provide valuable feedback.

Acknowledgments

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