Indirect 2D Touch Panning: How Does It Affect Spatial Memory and Navigation Performance?

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ABSTRACT
We present experimental work which explores the effect of touch indirectness on spatial memory and navigation performance in a 2D panning task. In this regard and based on the theory of embodied cognition, prior work has observed performance increases for direct touch input over indirect mouse input. As indirect touch systems gain in importance, we designed an experiment to systematically investigate the effect of spatial indirectness while maintaining the proprioceptive and kinesthetic cues provided by touch input. In an abstract search task, participants of our study navigated a 2D space and were asked to reproduce spatial item configurations in a recall task. Our results indicate that spatial memory performance is not decreased by a spatial separation of touch input gestures and visual display. Further, our results suggest that decreasing the size of the input surface in the indirect condition increases the navigation efficiency.

Author Keywords
Touch; multi-touch; indirect touch; panning; spatial memory; navigation; user study; embodied cognition.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
In this paper, we explore the influence of indirect touch input onto the user's spatial memory and navigation performance for 2D panning operations. Based on findings from the field of *Embodied Cognition*, positive effects of direct touch interaction on spatial memory performance have been observed compared to mouse input [11, 6]. However, it remains an open question if these benefits can only be observed in direct touch systems where input and display spaces coincide, or also in indirect touch systems, where input and display spaces are separated.

Indirect touch input systems have been used for decades in the form of touch pads or graphic tablets and *indirectness* has been recognized as one factor able to mitigate shortcomings of direct touch interaction (e.g. occlusion and covering large distances [3], arm fatigue [10] etc.). Examples for such systems include prototypes for novel interactive workspaces that integrate a touch screen into the desktop surface (e.g. [1, 15, 14]), automotive interfaces that aim to leverage touch input without drawing the driver's attention away from the street [2] or mobile interaction with interactive walls [4]. Recently, Apple introduced an indirect touch mode for the iPad's QuickType keyboard that lets users transform the keyboard into a touch pad for controlling a cursor to ease text selection.

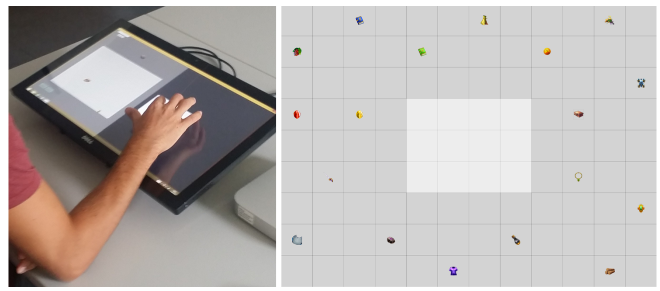

Figure 1. Left: A participant of our experiment performing 2D panning with a virtual touch pad. Right: The visual grid with one spatial item configuration. The highlighted empty grid cells in the center represent the home position.

2D panning is a frequent task in both desktop computing environments and touch-based user interfaces. Examples include the navigation of large information spaces (e.g. maps) or operating continuous controls (e.g. sliders). While the literature reports benefits of direct touch input compared to indirect mouse input for the user's spatial memory [11, 6], the exact reason for this effect is unclear, as previous comparisons not only involved a difference between feedback cues provided by mouse operation and touch gestures as well as different input-/output-space configurations (spatial coincidence vs. separation), but also a difference between interaction styles (direct vs. indirect cursor-based object manipulation).

In this paper, we contribute new experimental data gathered in an experiment during which we explored the influence of different touch input configurations on spatial memory and navigation performance in a 2D panning task. In particular, we found that

- separating the touch input from the visual display and decreasing the touch input surface size does not seem to reduce spatial memory performance,

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- decreasing the touch input surface size in the indirect condition increases navigation efficiency,

- participants prefer indirect touch input over direct touch input for preventing occlusion, but also prefer larger input areas over smaller ones.

RELATED WORK

The implications of the *Embodied Cognition* theory have been of increasing interest to the HCI community. The assumption that both our mind and body co-evolve and that proprioception, kinesthetics and the according parts of the brain develop as a unitary system [7] has led to the observation of strong effects of body movements on cognition. In this regard, the role of kinesthetic cues, i.e. cues derived from parts of the body's position with respect to itself or to the environment, provided by mouse and touch input for spatial cognition has been researched by Tan et al. in 2002 [11], who studied a memorization task that involved dragging objects onto previously memorized positions, comparing mouse and touch input on a vertical display. Their observations indicate a significantly improved memorization performance for touch input.

In 2012, Jetter et al. [6] conducted a similar experiment which involved 2D panning as well as panning and zooming navigation and compared mouse and direct touch input on a tabletop display. Their results indicate significantly increased navigation and memorization performances for panning. However, the particular role of the kinesthetic cues provided by the touch input remains unclear, because not only the level of input device *directness* varied, but also the interaction style: in contrast to direct touch input, mouse input controls a cursor and involves a non-linear transfer function. Therefore, we wanted to explore if the spatial memory and navigation performance gains of direct touch persist if the touch gestures occur spatially separated from the display (i.e. *indirectly*).

Several studies have explored characteristics of indirect touch input: Schmidt et al. [9] compared direct and indirect multitouch input on a large 1:1 horizontal/vertical dual surface setup. In contrast to the relative mapping of the panning task in our study, they explored an absolute mapping for pointing and dragging tasks. Subsequently, Voelker et al. [13] evaluated different strategies to implement a tracking state for indirect touch in such setups and found lift-and-tap to be the most promising. In the context of interactive workspace ergonomics [14], Voelker et al. introduced gaze-based mode switching between input device and display mode, in order to turn the horizontal touch screen into an input device only when vision is centered on another display [12].

Gilliot et al. [5] explored the influence of input surface form factors on indirect target selection tasks with an absolute mapping and found that decreasing the input surface size improves target selection accuracy and that diverging aspect ratios between input and display areas decreases it. In contrast to target selection with an absolute mapping, we are interested in 2D panning with a relative mapping, as position input with relative touch mappings is widespread, yet not fully understood: recently, Nancel et al. [8] have investigated the influence of clutching on indirect touch pointing tasks using an embedded touch pad with different transfer functions. They found that, while clutching is often regarded as a necessary disadvantage for pointing tasks with small input spaces, clutch-less movements are more error-prone and harder to perform.

As physical input space seems to be an important property when designing indirect touch input techniques, we are interested in how decreasing the input surface size in the indirect condition influences memory and navigation performance in a 2D panning task. This is particularly interesting as in many cases the input device is either smaller than the display (embedded touch pad, smartphone), or a partition of a larger input surface into smaller virtual touch areas may be benefitial (e.g. for bimanual input [1]).

EXPERIMENT - THE PANNING UI

The goal of the experiment was to test whether the improved navigation and spatial memory performance with direct touch compared to the mouse reported by Jetter et al.[6] can also be observed with indirect touch input. We conducted an experiment similar to the one decribed in [6] with the following research questions:

RQ1 How will the spatial separation of visual display and touch input movements affect navigation and spatial memory performance in a 2D panning task compared to direct touch?

RQ2 How will a decreased input area size affect navigation and spatial memory performance when using indirect touch?

The experiment was based on an abstract panning task which simulated a user interface with a spatial layout exceeding the actual screen size (e.g. as in map navigation).

Participants

We recruited 18 participants (10 female) aged 18 to 43 (mean 26.11, SD = 6.63), all right-handed and using touch input devices (smartphones, tablets) on a regular basis. 15 were students (3 from a technical/computer science program), two were researchers (computer science and physics) and 1 was a Librarian. Participants were compensated either with a voucher for an online retailer or extra credits for their study program.

Apparatus and Conditions

We used a conventional 23" touch screen by Dell (ST2340) with a resolution of 1920x1080 pixels. The software realizing the touch panning task was implemented using JavaFX. As we wanted to test spatial memory performance, it was important to keep the visual frame of reference constant. Therefore, we opted for a horizontal screen orientation, since this allowed participants a physically less exhausting interaction than a vertically oriented display (Figure 1 left).

The experiment asked participants to navigate a view (800x600 pixels, 212.2x159.1 mm) using panning operations.

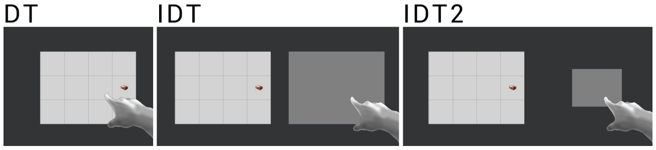

Figure 2. The three different input conditions used during our experiment.

In the direct touch condition (*DT*), participants used their fingers to touch and scroll the canvas. In the indirect conditions the canvas was navigated using touch gestures applied on virtual touch pads displayed on the right side of the canvas. In the first indirect touch condition (*IDT*), the virtual touch pad size and aspect ratio equalled the size of the view and in the second (*IDT2*), the virtual touch pad was uniformly scaled with the factor 0.5 (106.1x79.5 mm) (Figure 2). We used a linear transfer function with a gain factor of 1 across all conditions. Further, scrolling inertia was always disabled, since its influence on spatial cognition could not be assessed.

As in [6], the view displayed a part of a 12 by 9 grid with a spatial configuration of 18 items (Figure 1 right). The total size of the grid was 2400x1800 pixels (636.2x477.2 mm), but at any time only a clipping of 800x600 pixel (212.2x159.1 mm) was visible. The grid cells in the center of the canvas served as home position and did not display items. The items were taken from a coherently designed open source game asset package [1]. Three spatial configurations of the items were designed, based on manually altered random configurations in order to avoid obvious memorization strategies (e.g. all weapons are left). Further, three item subsets were chosen as search sequences for the spatial item configurations, each with a comparable optimal search path length (between 1856 and 1989 mm) and spatial distribution (same amount of items at borders).

Navigation and Spatial Memory Tasks

The experiment involved two tasks for every condition: (1) a navigation task that involved searching items located within the canvas and (2) a recall task that asked participants to reproduce the spatial configuration of the items within the canvas. Their structure and measures follow the ones presented in [6].

Navigation Task

In the navigation task, participants were asked to repeatedly navigate through a sequence of items. The next item of the sequence always appeared in a pop-up window in the top center of the display and participants first had to click on this pop-up, then navigate to the item starting from the current position of the grid and finally click on it. We did not start each search from the same position as we felt that a consecutive search would better fit real world tasks and we controlled distances by calculating optimal search paths and designing tasks with comparable path length. In this manner, a sequence of 8 of the 18 items had to be searched and the sequence was repeated 8 times (8 blocks), resulting in 64 search trials. In the beginning of the navigation task, the spatial configuration of the items was completely unknown to the participants. However, through the repetition of blocks, they were given the chance to memorize the spatial distribution of items across the canvas and improve their mental representations and navigation paths. This short-term memorization of the item locations was intended to compare navigation performance across participants. However, we asked to maximize for speed to prevent intensive memorization strategies.

We measured efficiency and task completion time based on timestamps and XY-coordinates of the pure panning operations (excluding clicks on items). Navigation efficiency was calculated as the ratio between the actual panning distances from the participants and the optimal, shortest panning distance. Therefore, an optimal performance would result in a ratio of 1.0, while decreasing performance would increase this measure. The optimal navigation paths were calculated for each search sequence as the minimum amount of grid movement needed to bring the bounding box of each icon of the search sequence into the visible area of the grid.

Spatial Memory Task

In the spatial memory task, a random sequence of the 8 items from the navigation task was shown to the participants and they had to place each item at its original position within the grid. The placement was done using the arrow keys from a keyboard in order not to involve unconscious use of motor or kinesthetic memory. The participants did not receive any feedback indicating the accuracy of their placements and for each item they started over with an empty grid in the home position. We measured the Euclidian distance in millimeters between the participant's item placement and its original position and asked the participants to be as accurate as possible.

Procedure

We designed a within-subjects experiment with input modality as counterbalanced independent variable with the levels *DT*, *IDT* and *IDT2*. Therefore, each participant had to perform both the navigation and the recall task three times. In the beginning of the experiment, demographic data was collected with an online survey. Then, there was a short introduction phase, during which the experimenter explained the nature of both the navigation and the recall task as well as the input conditions by demonstrating the application running on the touch display. For every input modality there was a training phase, during which the participants performed a short version of the navigation task (1 block) with a different icon set. Then, the data was collected during the actual navigation, followed by the recall task. Between each condition, participants watched a three-minute cartoon video to relax. Upon completion of the experiment, we asked the participants for their preferred input condition.

Results for Spatial Memory Performance

For *DT*, the mean placement error was 104.9 mm (SD = 47.4), for *IDT* it was 101.6 mm (SD = 49.5) and for *IDT2* it was 112.1 mm (SD = 49.1). A repeated measures ANOVA determined that the mean spatial memory performance did not differ statistically significantly between input styles ($F(2, 34) = 0.333$, $P = 0.719$).

[1] http://opengameart.org/content/basic-rpg-item-icons-free

Results for Navigation Performance

To consider learning, we compared navigation efficiency and time for all three input conditions with block as factor (figure 3 shows the navigation efficiency across blocks). Due to a non-normal distribution of the data (Shapiro-Wilk Tests), we performed Friedman tests. Post hoc analysis results (Wilcoxon signed-rank tests, Bonferroni corrected with sig-level set at $p<0.007$ as we compared 8 consecutive blocks) show that time and navigation efficiency improvements are not significant after block 4 (time) and 3 (efficiency) across all input conditions. Therefore, further analysis is based on data from block 4-8 for time and 3-8 for efficiency.

As efficiency ratios were not normally distributed, we conducted a Friedman test with input condition as factor. Post hoc analysis results (Wilcoxon signed-rank tests, Bonferroni correction applied with sig-level set at $p<0.017$) show a significant difference between IDT2 (1.83, SD = .58) and IDT (2.14, SD = .63) ($U = -2.766$, $p = 0.006$) as well as DT (2.39, SD = .98)($U = -3.245$, $p = 0.001$), but not between DT and IDT ($U = -1.263$, $p = 0.207$).

A repeated measures ANOVA with input condition as factor and time as dependent variable (normally distributed, log10(time) because raw data was positively skewed) shows no significant differences ($F(2,34) = 0.896$, $p = 0.417$) between DT (30.31 s, SD = 9.98), IDT (28.74 s, SD = 8.22) and IDT2 (27.49 s, SD = 9.17).

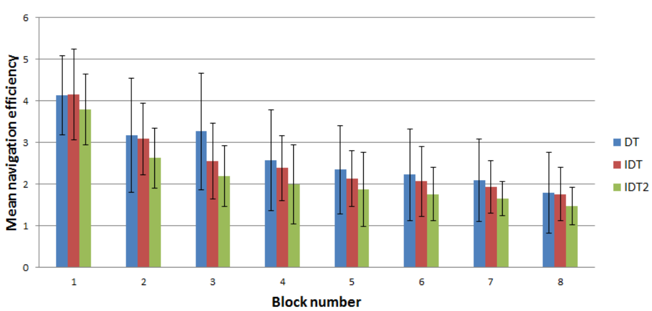

Figure 3. Navigation efficiency per input condition based on panning distance (error bars indicate standard deviation).

Participants' Personal Preferences

14 of the 18 participants stated that they preferred *IDT*, 2 preferred *DT* and 1 *IDT2*. The most important reason given for the preference of *IDT* was the improved overview compared to the occlusion in the direct touch condition (n=12).

DISCUSSION

Our results show that separating touch input from visual output will not per se result in a decreased spatial memory or navigation performance in a 2D panning task. In particular, they indicate that the relation between haptic and kinesthetic cues provided by touch gestures and spatial memory performance does not depend on the spatial coupling between the input movement and the visual object movement as long as the direct coupling between them is maintained. As Jetter et al. [6] could not observe spatial memory performance gains for touch when involving zooming (logarithmic transfer function) , it remains open how the introduction of faster and nonlinear transfer functions will affect memory performance for indirect touch panning. Interestingly, we observed a higher error rate during the spatial recall task compared to [6], which could be due to the difference in display size.

The increased navigation efficiency we observed with the smaller input surface size was surprising, as the linear non-gained transfer function required more clutching and restricted the panning movement length. While Nancel et al.'s findings [8] are based on a variation of transfer functions and a constant input surface size, our observations indicate similar effects for a constant transfer function and varying input area sizes.However, the efficiency gain is not reflected in subjective ratings of the participants, who preferred the larger input area size. More research is necessary to better understand why navigation was less efficient with the larger input area size and with direct touch.

In an effort to replicate the study design of [6], we did not control task difficulty. Still, our time measurements indicate that the increased navigation efficiency with a smaller touch pad does not necessarily go along with increased task completion times.

FUTURE WORK

While the spatial separation of input and output surfaces was restricted to the display plane in our experiment, future work could explore if the observed effects persist in settings where this is not the case. This is especially interesting for interactive workspaces featuring multiple, differently aligned displays where horizontal touch displays act as input devices. As such devices have display capabilities they can show arbitrary virtual touch pads. An example for such an approach is exhibited by the Magic Desk prototype [1], which features a multi-purpose touch pad for the non-dominant hand. On the one hand, this seems to be an opportunity to design virtual input devices tailored to both specific applications and finger input. On the other hand, understanding the influence of indirect touch mappings and input area form factors on human performance and cognition is crucial to inform the design of such user interfaces. Therefore, future work could explore indirect control-to-display mappings for 2D panning tasks more systematically, for example by looking at conditions with various input sizes and form factors or faster transfer functions. Also, the role of different feedback cues could be explored more systematically, e.g. by separating haptic and kinesthetic cues (e.g. in a hovering condition).

CONCLUSION

We have presented experimental work which explores the effect of touch indirectness on spatial memory and navigation performance in a 2D panning task. Our results indicate that spatial memory performance is not decreased by a spatial separation of touch input gestures and visual display, and therefore primarily relies on the involved proprioceptive and kinesthetic cues provided by touch input. Further, our results suggest that decreasing the size of the input surface in the indirect condition increases the navigation efficiency.

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