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An Experimental Comparison of Vertical and Horizontal Dynamic Peephole Navigation

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ABSTRACT
Dynamic peephole navigation represents a technique for navigating large information spaces in an egocentric way. Studies have shown cognitive benefits for a vertical peephole orientation, when compared to non-egocentric interaction styles. To see how the aspect of canvas orientation effects user performance, we conducted a study (N=16) which revealed that canvas orientation has no significant effect on either navigation performance or spatial memory. We also found a significantly lower physical demand and a higher mental demand in the horizontal orientation. For short-term activities we therefore propose a vertical orientation, while for long-term activities horizontal dynamic peephole navigation is more suitable.

Author Keywords
Dynamic peephole navigation; canvas orientation; spatial memory; subjective workload; navigation performance.

INTRODUCTION

One way to handle large datasets is by provisioning movable viewports, so-called dynamic peepholes, which allow the user to explore information spaces in an egocentric way. Instead of panning the screen content (e.g. a city map), the user physically moves to off-screen content (e.g. a neighboring city) as if it were situated in physical space (Figure 1). Studies on this technique (e.g. [3,4,5]) show cognitive benefits for a vertical peephole canvas when compared to non-egocentric interaction styles. In some situations, however, a horizontal orientation may be more practical. Consider the following scenario:

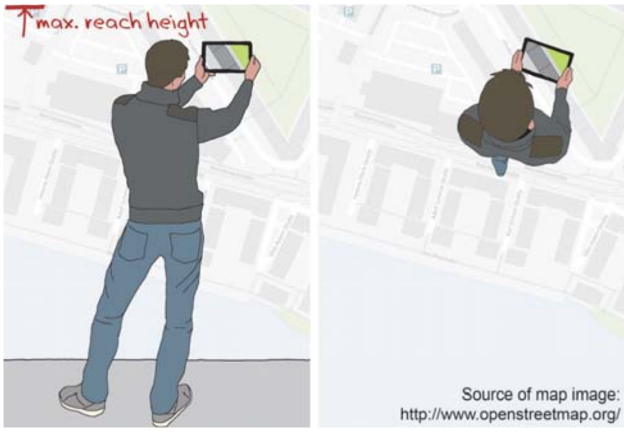

Figure 1. Navigating a virtual map on a vertical (left) and a horizontal (right) peephole canvas. A tablet serves as a peephole which can be moved to explore off-screen content.

A multidisciplinary team of urban planners[1] meets in an office to work on a large project. The meeting is supported by a horizontally oriented, large-scale peephole canvas which shows the construction site. Via a tablet, each team member navigates the site and works on their individual spot. The architect privately evaluates their drafts of a barrier-free entrance of a particular building on their tablet. The architect then publishes one design on the canvas so that others can see it. The civil engineer, who is dependent on the architect's design, now sees the published design on the peephole canvas and picks it up to work on it later at the office. At the end of the meeting, all modifications are highlighted on the canvas and are discussed by the team.

Scenarios like the one above may require a large peephole canvas. In this case, a horizontal canvas orientation seems more practical than a vertical one, because the canvas size is not restricted by the persons' reach height (Figure 1, left). In addition, a horizontal canvas orientation does not occlude as much of the interaction space as a vertical orientation does (compare Figure 1, left and right).

[1] https://www.planning.org/aboutplanning/

While some properties of peephole navigation are well explored (e.g. peephole size and the optimal number of horizontal canvas layers [8]), the aspect of canvas orientation and its effects on human cognition is still unexplored. This note reports findings of an experimental comparison on a single-user navigation task between vertically and horizontally oriented canvases.

BACKGROUND AND RELATED WORK

In 1993 Fitzmaurice [1] introduced the Chameleon prototype, a spatially-aware palmtop that served as a dynamic peephole to navigate virtual information spaces. As a continuation of the Chameleon, Yee [11] presented a peephole prototype to create and manipulate virtual objects. A usability test showed that the technique "can be more effective than current methods for navigating information on handheld computers." Spindler et al. [10] presented PaperLens, a projection-based peephole prototype to navigate information spaces spanned above the tabletop.

Comparative studies (egocentric vs. non-egocentric)

Mehra et al. [4] compared the perception of line lengths for static and dynamic peepholes and found that dynamic peephole navigation results in a significantly better line length discrimination. Kaufman and Ahlström [3] compared user performance of vertical peephole interaction (via a projector phone) with touch-based input (via a smartphone). While there were no significant differences in navigation performance, spatial memory performance was significantly better when participants navigated with the projector phone. Rädle et al. [5] compared vertical dynamic peephole navigation with touch navigation. Their study revealed an effect on navigation performance and long-term spatial memory in favor of egocentric navigation. Spindler et al. [9] investigated navigation speed for both traditional Pinch-Drag-Flick gestures and egocentric manipulation using a tablet and a smartphone. Their results show that spatial manipulation can significantly outperform traditional Pinch-Drag-Flick. Scarr et al. [7] provide an overview on spatial memory in user interfaces and discuss spatial reference systems as a crucial cognitive factor.

Studies on the properties of dynamic peephole interaction

Spindler et al. [8] investigated user performance for multi-layer interaction above the table. For horizontal search tasks they identified 44 layers as the maximal number. Rädle et al. [6] investigated the effect of the peephole size on a vertical canvas. They identified the tablet as "sweet spot" in terms of peephole size and both user navigation performance and user task load.

Thus, assuming that 1) dynamic peephole navigation on a vertical canvas provides cognitive benefits compared to non-egocentric techniques and that 2) a horizontal canvas orientation has practical advantages in certain scenarios, the question raised by this paper is how the orientation of the peephole canvas affects user performance.

EXPERIMENT

We conducted a controlled lab experiment to study the influence of the canvas orientation on user performance and task load. The experiment was designed as a counter-balanced within-subjects design with the peephole canvas orientation being the independent variable (Figure 2).

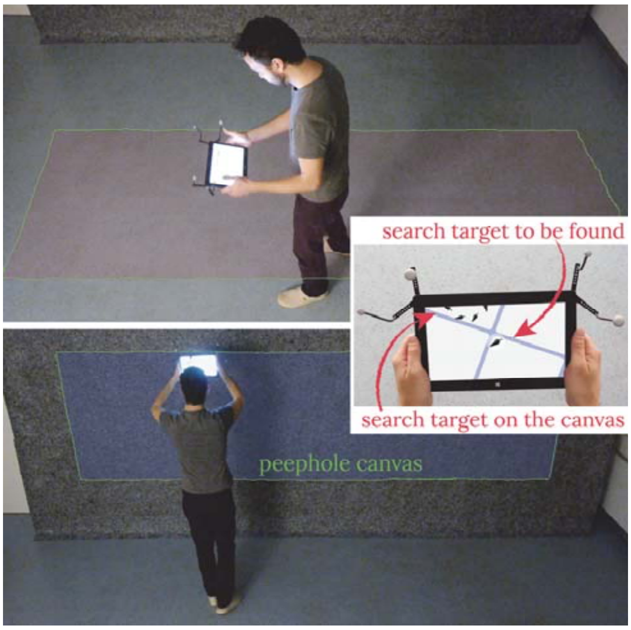

Figure 2. Two study conditions: Horizontal orientation of the peephole canvas (top) vs. vertical orientation (bottom).

In each condition participants were tasked to find a sequence of predefined symbols for which they had to navigate through the canvas by moving the peephole. For a peephole we used a tablet as it represents a sweet spot in terms of peephole size and both navigation performance and task load [6]. In contrast to [6] we did not simulate the peephole with a proxy device but used a real tablet in favor of external validity. The dependent variables are user task load (NASA TLX), navigation path length, navigation time, spatial memory, and qualitative data from a concluding, semi-structured interview and from video recordings.

Participants

16 participants (8 female, 8 male) were recruited for the experiment. The mean age was 25.5 years (SD = 4.39, min = 20 years, max = 38 years). 13 participants were students of which only one had a background in computer science; the other 3 were administrative staff.

Study Apparatus & Environment

As a tablet we used a Microsoft Surface 2 device (208ppi, 984 g, 1920*x*1080 pixels on 10.6″). The tablet was equipped with passive markers and tracked with an OptiTrack 3D motion capturing system (24 cameras, tracking rate = 100 Hz, tracking mean error < .5 mm).

Depending on the study condition, the orientation of the peephole canvas was either horizontal (parallel to the ground) or vertical (parallel to the wall; Figure 2). Canvases had a physical dimension of 292*x*82 cm, a resolution of 23891*x*6709 pixels and a control-display gain of 1 to make navigation as natural as possible. In contrast to [6], rotation was enabled around the axis orthogonal to the canvas.

Task Design

Each canvas contained 20 distinct symbols (*targets*). From the 20 targets only 8 were defined as *search targets*, all others served as distractors. For the targets we used symbols from the Wingdings font as in [5]. The study task consisted of a search task and a reconstruction task.

In the *search task*, participants had to find the 8 search targets in a pre-defined order (8 targets = 8 trials = 1 block). To confirm a search target and to continue with the next trial, participants had to center the matching target on the tablet display (Figure 2, center right) and touch the display. Each block was repeated 8 times resulting in 64 trials.

In the *reconstruction task*, participants had to recall and reconstruct the location of the 8 search targets, again using the tablet. They were exposed to a plain canvas, i.e. all targets had been removed from the canvas. The search targets were displayed on the border of the tablet display and participants had to physically move and "drop" each search target at its presumed location. Locations could be changed by re-dropping a target at a different location.

Procedure

First, participants filled out a demographic questionnaire. We then asked the participants to hold the tablet up in the air to individually optimize the position of the vertical peephole canvas. Afterwards the task was introduced to the participants. To make sure that participants were able to adequately perform the study task from the beginning, they were provided a training phase (approx. 3 min.) in which they could familiarize themselves with the technique.

Participants then began with the study task (approx. 14 min. in each condition). Afterwards, they were provided the NASA TLX questionnaire. Attached to the questionnaire there were several paper-based mazes. They were given 5 minutes to fill out the questionnaire and to continue with the mazes in case they finished the TLX early. The mazes were meant to distract participants from keeping the locations for the subsequent reconstruction task in their short term or working memory. After 5 minutes, participants were asked to reconstruct the locations of the search targets (approx. 14 min.). After participants had finished the reconstruction task, the study task was repeated in the respective other condition. After the completion of the study task in both study conditions, participants were asked about their preferred canvas orientation by a semi-structured interview. The entire procedure took approx. 60 minutes. Participants were compensated with 10 Euros.

RESULTS

For *user task load*, a pairwise comparison in the NASA-TLX revealed a significantly lower mental demand ($p < .05$) in the vertical condition (M = 37.81, SD = 20.24) than in the horizontal condition, (M = 50.31, SD = 22.09) whereas the physical demand was lower ($p = .017$) in the horizontal condition (M = 29.69, SD = 20.36) than in the vertical condition (M = 47.81, SD = 24.21) (Figure 3). The mean values of all other dimensions were not significantly different.

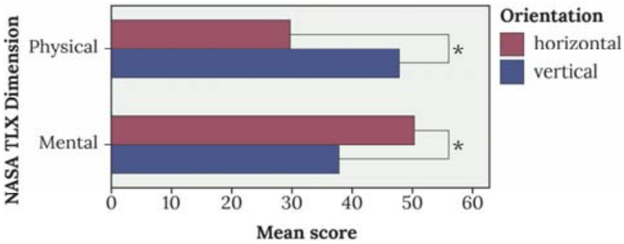

Figure 3. Task Load in the two dimensions in which significant differences occurred.

For *path length* an ANOVA showed that the peephole canvas orientation had no significant effect ($F_{1,15} = 1.468$, $p = .244$, *partial* $\eta^2 = .089$) (Figure 4).

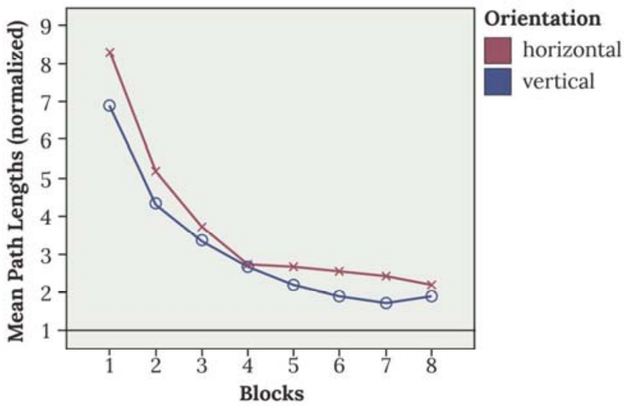

Figure 4. Normalized path lengths across all 8 blocks.

For *navigation time* an ANOVA showed that peephole canvas orientation had no significant effect ($F_{1,15} = 1.680$, $p = .214$, *partial* $\eta^2 = .101$).

For *spatial memory* an ANOVA showed that peephole canvas orientation had no significant effect ($F_{1,15} = 3.854$, $p = .068$, *partial* $\eta^2 = .204$).

Analysis of *qualitative data* revealed that 10 out of 16 participants preferred the vertical condition, with 7 reporting that less freedom of movement provided them with better orientation. From the 6 participants who preferred the horizontal condition, 4 justified this with a more comfortable operation and 2 with a higher degree of freedom. As an orientation-independent *recall strategy*, 5 participants reported having actively used the boundaries of the peephole canvas. In the vertical condition 5 participants reported to have mentally subdivided the canvas (e.g. left/right, upper/lower half). In the horizontal condition, 3 participants reported that the sequence of footsteps helped in retaining the target location and 3 reported that they tried to retain the directions between the angles of the targets.

Analysis of video recordings yielded two major *movement patterns* in the horizontal condition: 13 of 16 participants did not use rotation at the beginning of the search task; instead they moved either sideways or back and forth. 9 of these 13 participants started to use rotation at some point, stating afterwards that they first had to attain a mental map of the canvas before moving freely (*'I first started turning around when I had the map in my head'*; *'As I achieved an overview at some time, I broke out and became more playful'*). 4 participants did not use rotation at all in the horizontal condition, as they feared to lose orientation (*'I would have lost orientation, if I had turned around'*).

DISCUSSION AND LIMITATION

In the vertical orientation, navigation was based on two major components: walking along the virtual canvas and vertically moving the tablet. In the horizontal orientation, however, only walking was required to navigate the entire canvas. This probably caused a lower *physical demand* in the horizontal orientation. The increased *mental demand* in the horizontal orientation resonates with both the observed movement patterns (participants initially avoided rotations) and participants' report on an initial lack of orientation. It can therefore be hypothesized that the increased *mental demand* results from an additional degree of freedom (yaw rotation) and decreases with the establishment of a mental map. This could be subject of further research.

The limitation of this study refers to the aspect of physical reference systems [7]: In fact, we sought to minimize their effect (e.g. by providing a homogenous physical background of the canvases). Yet, we cannot guarantee that some remaining features (e.g. window frames) might have been more conducive to either of the two conditions.

IMPLICATIONS

For short-term activities that do not require much space, a vertical canvas orientation is more suitable than a horizontal one as the physical demand plays a minor role and quick orientation keeps the mental demand at a low level. For long-term activities that require vast spaces–e.g. spatial planning activities–a horizontal canvas orientation is more suitable due to the lower physical demand. Supporting the establishment of a mental map, however, is crucial to reduce mental effort at an early stage. This could be achieved by providing the user a virtual reference system such as the Wedge visualization technique [2].

CONCLUSION

In this paper we compared the effects of the peephole canvas orientation on user task load, navigation, and spatial memory performance. The results of our study suggest that the differences in navigation performance and spatial memory are minor. In addition, navigating the horizontal canvas was reported to be less physical demanding than the vertical canvas. For long-term activities that require a large canvas we therefore consider a horizontal canvas orientation a promising alternative. Yet, horizontal navigation yielded a higher mental demand due to an initial lack of orientation, which, however appeared to decrease with a growing mental map of the canvas. For short-term activities that do not require a large canvas we therefore propose a vertical canvas orientation.

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