# Navigating on handheld displays: Dynamic versus Static Keyhole Navigation

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**DOI**
10.1145/1188816.1188818

**Publication date**
2006

**Document Version**
Final published version

**Published in**
ACM Transactions on Computer-Human Interaction (TOCHI)

# Navigating on Handheld Displays: Dynamic versus Static Peephole Navigation

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Handheld displays leave little space for the visualization and navigation of spatial layouts representing rich information spaces. The most common navigation method for handheld displays is *static peephole navigation*: The peephole is static and we move the spatial layout behind it (scrolling). A more natural method is *dynamic* peephole navigation: here, the spatial layout is static and we move the peephole across it. In the experiment reported here, we compared dynamic and static peephole navigation in otherwise similar conditions. Subjects viewed a spatial layout containing two lines on a static display screen. Only a part of the screen—the peephole—was visible. Subjects had to discriminate line length by either moving a dynamic peephole across a static layout of the lines or by moving a dynamic layout behind a static peephole. In both conditions, they used mouse-cursor control to move either the peephole or the lines.

Results show significant differences in discrimination performance between conditions when lines are larger than the size of the peephole. Discrimination thresholds for static peephole navigation were 50–75% higher than for dynamic peephole navigation. Furthermore, static peephole navigation took 24% more time than dynamic peephole navigation.

Categories and Subject Descriptors: H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*Graphical user interfaces, evaluation/methodology*

General Terms: Design, Experimentation, Human Factors

Additional Key Words and Phrases: Human-computer interaction, handheld displays, navigation, visual perception

## 1. INTRODUCTION

Today, handheld computers serve as viewing portals that visualize rich multimedia information spaces. At the convenience of mobility, their screen sizes are very small, leaving little room for spatial organization. However, such spatial organization of information is essential and exploits human capabilities of spatial memory [Robertson et al. 1998]. Thus, we need methods to virtually increase the screen size; the most widely applied method is scrolling. With

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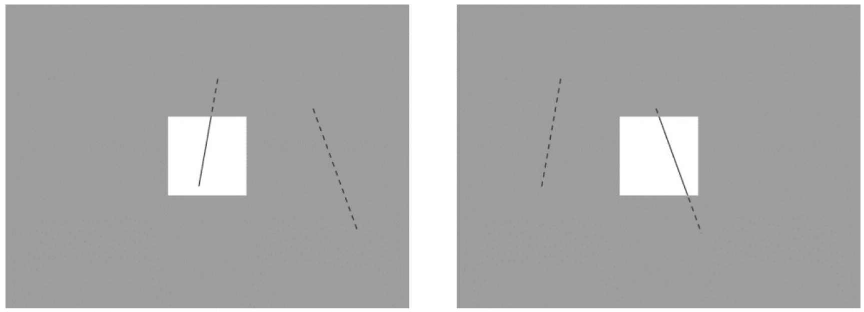
scrolling, we perceive and navigate spatial layouts by moving the layout behind a *static peephole.* This, however, results in a loss of overview and inefficient navigation [Guiard et al. 2004]. A more natural condition is to move the peephole across the spatial layout, which we call *dynamic* peephole navigation. This way, information does not change location, allowing users to rely on their spatial memory.

With dynamic peephole navigation, the position of the screen determines what part of the layout is visualized. Implementation requires the use of location sensors or tracking techniques. Implementations of dynamic peephole navigation with head-mounted screens were first seen in virtual reality applications [Sutherland 1968], and it has been shown experimentally that such VR conditions enhance spatial learning and spatial orientation [Bakker et al. 2003]. Fitzmaurice et al. [1993] were the first to apply tracking techniques to handheld screens, coined spatially-aware handheld displays. Yee [2003] extended this work by combining spatially-aware displays with pen input and carried out usability studies to determine the functionality in various one- and two-handed interaction tasks, ranging from list selection to note taking and drawing. Task times and error rates showed that dynamic peephole techniques can be more effective than current methods for navigating information on handheld computers.

Our study aims to provide further support for the benefits of dynamic peephole navigation by isolating perceptual performance in tightly controlled conditions. We investigated the perception of simple features of spatial layouts under dynamic and static peephole navigation. For this experiment, we have chosen line length. The reason for this is twofold. First, the distance between two information items in a spatial layout representing an information space is often used as an indication of the similarity or relation between the items [Nguyen and Worring 2004]. Second, much is known about human line-length perception [Wagner 1985; Norman et al. 1996], allowing an adequate design and discussion of the experiment.

Our experiment is a line-length discrimination experiment in which the lines are viewed through a peephole such that only part of a line is visible at any moment. Subjects have to discriminate line length by either moving the peephole across static lines (dynamic peephole navigation) or moving the lines behind the static peephole (static peephole navigation). In both conditions, they used mouse-cursor control to move either the peephole or the lines. Thus, arm and hand movements (proprioceptive cues) are similar in both conditions. Differences in performance cannot be explained in terms of these proprioceptive cues, but only in terms of underlying cognitive processes, in this case, human spatial and temporal memory functions. In the dynamic peephole condition, lines that are longer than the peephole have to be integrated over time (temporal integration) in order to construct an internal representation of the spatial layout and estimate the line length. For the static peephole, however, the lines have to be integrated over time as well as over space (spatiotemporal integration) due to the changing positions of the lines. For this reason, we expect that the more natural dynamic peephole navigation leads to faster and more accurate perception of spatial structure than static peephole navigation. If so, dynamic



(a) (b)

Fig. 1. Static peephole navigation. The gray square represents the screen. The white square represents the static peephole. The layout consists of two lines of which only the solid parts are visible through the peephole. The dashed parts are not visible in the experiment. By moving the layout from the starting position (a) to another position (b), other parts of the lines become visible through the peephole.

peephole navigation is likely to improve performance for any interaction task in which the spatial relationships of the scene are important.

## 2. METHOD

### 2.1 Design

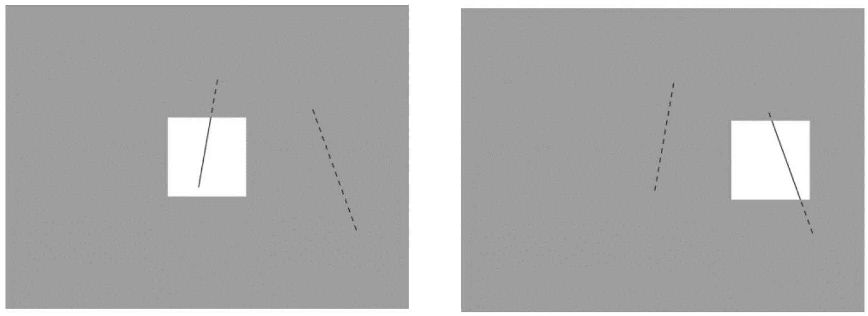
In our line-length discrimination experiment, the lines are viewed through a peephole such that only part of a line is visible at any moment. To study the effects of different peephole navigation methods, two factors were manipulated: type of peephole navigation and the line length. The experiment design was within subjects for all factors.

The first factor, peephole navigation, was manipulated within subjects and had two levels: (a) static peephole manipulation, and (b) dynamic peephole navigation. As described earlier, in the static condition the peephole remains at a fixed position as stimuli scroll into or out of view. By contrast, in the dynamic condition the peephole itself is moved, instead of the underlying information. See Figure 1 for an illustration of the static peephole condition and Figure 2 for that of the dynamic peephole condition.

In the static peephole condition, the subject views the first line Figure 1(a). By moving the mouse-cursor, the subject encounters the second line Figure 1(b). Note: The mouse movement leads to a change in the peephole view. The peephole position, however, remains unchanged.

In the dynamic peephole condition, the subject views the first line Figure 2(a). By moving the mouse-cursor, the subject encounters the second line Figure 2(b). Note: The mouse movement leads to a change in the peephole view, *as well as* in its position.

The second factor, line length, was also manipulated within subjects and consisted of three levels: short, intermediate, and long. The short lines were smaller than the peephole. The intermediate and long lines, however, were



(a) (b)

Fig. 2. Dynamic peephole navigation. The gray square represents the screen. The white square represents the dynamic peephole. The static layout consists of two lines of which only the solid parts are visible through the peephole. The dashed parts are not visible in the experiment. By moving the peephole from the starting position (a) to another position (b), other parts of the lines become visible through the peephole.

chosen such that they did not fit into the peephole and navigation was needed to view the lines completely.

The effects of the manipulations were measured by two dependent variables: (a) user responses, and (b) reaction time. Subjects were required to respond to a two-alternative forced choice question, denoting that either the left or right line appeared longer. The reaction time was measured from the onset of the stimulus presentation up to the moment the user gave a response.

### 2.2 Stimulus Material

A single trial consisted of comparing the lengths of two lines: the reference line and test line. Both lines were drawn in black on a white background (see Figures 1 and 2). The lines were only partly visible through the peephole (symbolized by the white square in Figures 1 and 2). The peephole had a fixed size of 6 cm by 6 cm. Outside the peephole the screen was black. One line centered in the left half of the screen, the other in the right half. It was chosen randomly which of the two lines (reference or test) was in the left half.

The exact centers of the lines were scattered slightly (uniformly within a range of 3 cm) in order to avoid artificial cues. The orientation of each line varied uniformly between 30 to +30 degrees. In no case did the lines intersect each other or the edge of the screen.

The length of the reference line could take three different levels: short (4.8 cm; 80% of the peephole size), intermediate (8.4 cm; 140% of the peephole size), or long (12 cm; 200% of the peephole size). The length of the test line varied from 75% to 125% of the length of the reference line (in increments of 5%, excluding the 100% increment). For each condition, we tested a set of 210 trials: 3 reference lengths $\times 10$ different test lengths $\times 7$ trials each. Thus, the subjects were presented 420 trials in total for the two conditions combined. The order of test lengths was randomized per reference length and the order of reference lengths was randomized within a condition. The order of condition was counterbalanced across subjects.

Subjects had a maximum of 10 seconds per trial to manipulate the position of the peephole with the mouse and to indicate whether the left or right line was longer by pressing a specific key. As soon as a response was given, the subject could proceed to the next trial by pressing the space bar. If no response was given within the 10 second timeframe, the peephole and stimuli were removed from sight and the subject was asked to give a response before proceeding.

### 2.3 Apparatus

The experiment was conducted in a light and sound attenuated room equipped with seven workstations. Each workstation consisted of a PC, a 15 inch LCD display (30.5 cm $\times$ 23 cm) with a resolution of $1024 \times 768$, a keyboard, and an optical mouse. The workstation presented the instructions as well as the stimulus material and recorded the responses. Subjects were placed 60 to 70 cm from the screen.

### 2.4 Subjects

A total of 36 psychology students of the University of Amsterdam, 10 males and 26 females, participated in the experiment. Their ages ranged from 18 to 34, with an average of 21.9 years ($SD = 3.4$). Subjects were compensated for their participation with either first-year course credit or a small financial reward.

### 2.5 Procedure

Subjects were received in the experimental location and placed in front of a workstation. Prior to the computer instructions, the experimenter verbally stressed the importance of the task in order to increase the subjects' commitment. Furthermore, high performance was stimulated by presenting a prize to the subject with the best performance.

Each experimental condition was preceded by 9 practice trials (3 trials $\times$ 3 stimulus sets). At the end of each experimental condition, subjects were asked to describe the strategy they used. The experiment was concluded with a short exit questionnaire. In total, the experiment took an average of 46.6 minutes ($SD = 10.3$).

### 2.6 Analysis

We want to quantify how well subjects can discriminate the length of a pair of lines, that is, the *discrimination threshold*. For this purpose, we adopt the well-known theory of signal detection [Green and Swets 1966] and treat a human subject as a measurement device with a standard deviation $s$. Now, let us present a subject with two lines (a test line with length $t$ and a reference line with length $r$) and ask the subject which one is larger. We assume that the measurement device is linear with line length and also assume Gaussian noise. Due to the noise, line $t$ will yield an estimation $e_t$ with a distribution

$$p(e_t|t) = \frac{1}{\sqrt{2\pi s^2}} \exp\left[\frac{(e_t - t)^2}{2s^2}\right].$$

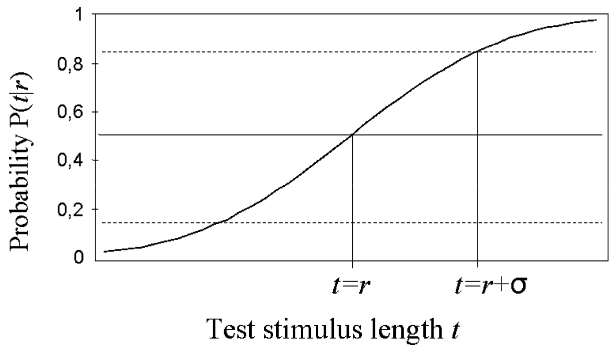



Fig. 3. Psychometric function: probability P(t|r) of judging the test line t to be longer than the reference line r. Parameter $\sigma$ is called the discrimination threshold.

Similarly, line $r$ will yield an estimation $e_r$ with a distribution

$$p(e_r|r) = \frac{1}{\sqrt{2\pi s^2}} \exp\left[\frac{(e_r - r)^2}{2s^2}\right].$$

The probability $P(t|r)$ that a subject will respond that $t$ is larger than $r$ as a function of $t$ equals the fraction of all occurrences for which $e_t > e_r$, that is,

$$P(t|r) = \int_{-\infty}^{\infty}\int_{e_r}^{\infty} p(e_t \mid t)p(e_r \mid r)de_t de_r$$

$$\text{or } P(t|r) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{t-r}{\sigma}} \exp\left[\frac{-z^2}{2}\right] dz, \text{where } \sigma = \sqrt{2}s.$$

Figure 3 shows this S-shaped curve P($t|r$) as a function of test length $t$. The curve is called the *psychometric function*. For $t = r$, the probability that $t$ is judged to be longer than $r$ is 50%. For $t = r + \sigma$, the probability is 84%.

Inversely, when we have measured the psychometric function (by varying test length $t$ for a given reference length $r$ and collecting answers), we can estimate the standard deviation $\sigma$. We call this standard deviation the discrimination threshold. So, the discrimination threshold is the difference in line length $t$–$r$ for which subjects answer "$t$ is longer than $r$" in 84% of the trials. This also equals $\sqrt{2}$ times the standard deviation of the human line measurement device. A detailed treatment of this method is found in Werkhoven and Snippe [1996]. For each subject, we computed the discrimination thresholds by fitting a psychometric function to the data per condition per reference line-length using MATHEMATICA 5.0.

For perceptual discrimination on many physical dimensions, the discrimination threshold is a constant fraction of the reference value [Weber 1965; Luce and Galanter 1963]. This constancy is known as *Weber's Law*. By taking the Weber-fraction $\sigma/r$ as the dependent variable for further analysis, we eliminate the trivial effect of line length on discrimination thresholds and articulate the effects of navigation conditions. High Weber-fractions mean that the

Table I. Average Weber Scores W in % and Reaction Times T

| Condition | Short | | Intermediate | | Long | | Marginals | |
|---|---|---|---|---|---|---|---|---|
| | W | T | W | T | W | T | W | T |
| Dynamic | 9.6 (7.5) | 3.7 (0.8) | 15.0 (7.0) | 4.6 (1.3) | 17.2 (14.2) | 5.1 (1.4) | 14.0 (8.1) | 4.5 (1.2) |
| Static | 8.8 (9.0) | 4.6 (1.1) | 22.4 (12.6) | 5.7 (1.4) | 30.1 (15.8) | 6.3 (1.5) | 20.4 (9.5) | 5.5 (1.3) |

The Weber scores and reaction times are in s per condition per line length. Values between brackets are standard deviations. N = 31.

standard deviation $\sigma$ (noise) is high compared to the reference length (signal) and indicate low discrimination performance.

To analyze whether the subjects differed in discrimination performance between the static and dynamic peephole conditions, we performed a 2 (Peephole Condition) $\times$ 3 (Line Length) factorial multivariate analysis of variance (MANOVA), with dependent variables of Weber-fraction and Reaction Time. Furthermore, to reveal which line lengths (short, intermediate, or long) differed from each other between peephole conditions, the analysis was completed with paired t-tests. A Weber-fraction outside the range of three times the standard deviation from the average for a specific condition was considered an “outlier” and excluded from further analysis.

## 3. RESULTS

For the results of the peephole conditions from the main study, the Weber scores of two subjects were identified as outliers and excluded from further analysis. Furthermore, three subjects performed exceptionally well on the task and were able to detect differences smaller than the 5% increments. Because the stimulus material was not designed for such small differences, the Weber scores could not be calculated reliably for these subjects and were therefore also excluded from further analysis. The following results are thus based on N = 31.

The MANOVA revealed that there was a significant effect of peephole navigation on discrimination performance. The average Weber scores with standard deviations are given in Table I. The *marginals* show the difference in performance between dynamic and static keyhole navigation, independent of the line length. On average, subjects performed significantly better ($F(1,25) = 20.83$, $p < 0.01$), indicated by lower Weber scores, in the dynamic peephole condition (W = 14.0%), rather than the static peephole condition (W = 20.4%). Additionally, an interaction effect between peephole condition and line length was significant ($F(2, 25) = 15.32$, $p < 0.01$), see Figure 4. The paired t-test revealed which line lengths differed from each other. Subjects' performance did not differ significantly on short lines. For intermediate and long line lengths, however, subjects did perform significantly better. In the dynamic peephole condition, we see a 50% increase in discrimination performance for intermediate line lengths compared to static peephole navigation, $t(30) = 3.94$ , $p < 0.01$. For long line lengths, we see a 75% increase, $t(30) = 4.02$, $p < 0.01$.

The MANOVA also revealed that there was a significant effect of peephole condition and line length on the reaction time. The average reaction times per line length are given in Table I and Figure 5. Subjects were significantly faster ($F(1,25) = 42.23$, $p < 0.01$) in the dynamic peephole condition (4.5 s) than in the

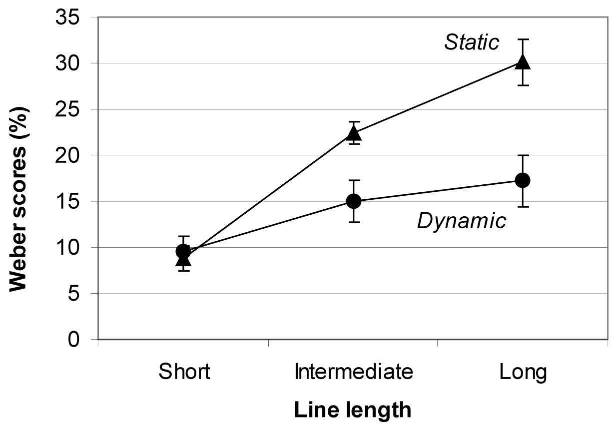



Fig. 4. Average Weber scores in percentage per condition per line length. Triangles: static peephole condition; circles: dynamic peephole condition. Error bars represent the standard error of the mean.

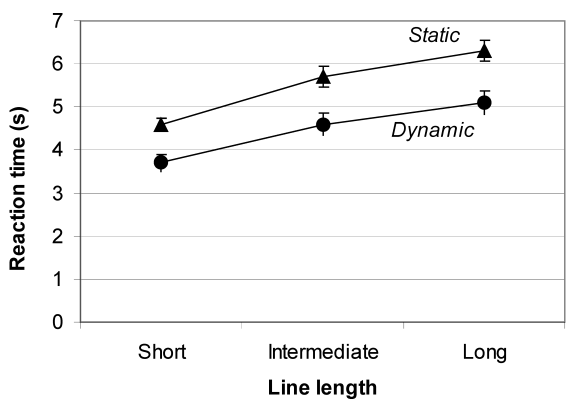



Fig. 5. Average reaction time per condition per line length. Triangles: static peephole condition; circles: dynamic peephole condition. Error bars represent the standard error of the mean.

static peephole condition (5.5 s). The paired t-test revealed that this held for the short and intermediate, as well as for long line lengths; $t(30) = 6.13$, $p < 0.01$, $t(30) = 5.93$, $p < 0.01$, and $t(30) = 6.19$, $p < 0.01$, respectively. On average the reaction times in the static peephole condition were 24% higher than those in the dynamic peephole condition.

To validate the experimental set-up, a control study was conducted in order to compare the baseline performance to findings reported elsewhere. Seven subjects were asked to perform the line comparison task *without* a peephole. Thus, these subjects were able to see both lines simultaneously. For this less difficult task the test stimulus differed in increments of 1% of the reference stimulus, instead of increments of 5%. All other aspects were identical to the experimental set-up of the main study. The results of the control study (see Table II) are in line with previous findings [Norman et al. 1996].

Table II. Average Weber Scores in Percentages (SD)

| Condition | Short | Intermediate | Long |
|---|---|---|---|
| No peephole | 5.4 (1) | 4.2 (3.1) | 4.4 (1.5) |

These scores are in the "no peephole" condition. N = 7.

## 4. DISCUSSION

The study shows that dynamic peephole navigation results in a significant improvement in discrimination performance. For static peephole navigation, intermediate and long line discrimination thresholds were 50–75% higher than for dynamic peephole navigation. This can be explained by the underlying cognitive processes. As mentioned in the introduction, dynamic peephole navigation relies on temporal integration alone, whereas for static peephole navigation, the lines have to be integrated over time as well as space (spatiotemporal integration). Because short lines fitted into the peephole, no integration was necessary to estimate line length and thresholds were 8.8% for the static and 9.6% for the dynamic condition. This finding is in line with the thresholds reported by Norman et al. [1996] for randomly-oriented lines. The thresholds they reported varied between 3% and 6%, but were taken at the 75% point of the psychometric function. Taken at the 84% point (our definition), their thresholds would have varied between 5.5% and 9%, in accordance with our results. The additional proprioceptive information available in our experiment, that is, mouse movements, apparently did not lower these discrimination thresholds.

Another conclusion that might be drawn from the study is that dynamic peephole navigation increases speed. There does not appear to be a tradeoff with performance; dynamic peephole navigation was associated with shorter reaction times, as well as increased discrimination performance, compared to static peephole navigation. In addition, 80% of the subjects indicated in an exit interview that they preferred dynamic peephole navigation over static peephole navigation. A small number of subjects also noticeably relied on a different strategy for dynamic as opposed to static peephole navigation. Instead of moving the mouse moderately slowly, as they did in the static peephole condition, they moved it very quickly. In extreme case of infinitely fast scanning movements, temporal integration would lead to blurring of the peephole, leaving a clear integrated view of the lines. In static peephole navigation, however, temporal integration would blur the lines and leave the peephole intact. It seems that the subjects intuitively made use of this beneficial aspect of dynamic peephole navigation.

Clearly, the results of this study support the work of Fitzmaurice et al. [1993] and Yee [2003] and suggest the use of dynamic peephole navigation for tasks where spatial relationships are important on devices with limited display size. Common tasks for which spatial relationships are important are, for example, map reading and drawing. We expect benefits in dynamic peephole navigation for these tasks when they have to be carried out on handheld displays. Another more specific task is the exploration of a landscape through a camera mounted under an unmanned aerial vehicle. Traditionally, cameras are controlled with a joystick and camera images are projected within a fixed window. Dynamic peephole navigation in this case could be realized by head slaved control of the camera direction in combination with head slaved projection of camera images. We expect a substantial increase in situation-awareness of the camera operator and better estimation of spatial relationships when using dynamic peephole navigation.

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Received April 2005; revised August 2005; accepted February 2006