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The Effect of Target Precuing on Pointing with Mouse and Touchpad

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Abstract. In point-and-click interfaces the location of targets is sometimes known to the user before visually identifying it, and sometimes not. This experiment investigates how pointing is affected by whether the target location is precued so that users know it in advance or non-precued so that users learn it only at the onset of pointing trials. We investigate this for young, adult, and elderly participants pointing with mouse and touchpad. Target precuing affects the trial completion time, the reaction time, the sheer movement time, and multiple movement kinematics. In addition, target precuing interacts with the use of either mouse or touchpad, with target distance, and with target size, but surprisingly little with participant age. Because the target location was always made known to participants no later than at the onset of the pointing trial, the effects of target precuing must be due to the different possibilities for mental and motor preparations.

Keywords: target precuing, pointing movements, mouse, touchpad, tapping tests, Fitts's law

1 Introduction

Pointing and clicking at user-interface objects are crucial for many tasks in graphical user interfaces. Consequently, researchers continually propose new techniques and devices for supporting pointing operations. An extensive body of research has consolidated the methodology of how to empirically study the relative merits of such proposals (e.g., Blanch & Ortega, 2011; MacKenzie, 1992; Soukoreff & MacKenzie, 2004; Wobbrock, Shinohara, & Jansen, 2011). This body of research typically uses or extends the Fitts's law paradigm (Fitts, 1954; MacKenzie, 1992). Within this paradigm targets that the user should select are visually indicated, while systematically varying the width of targets and the distance the user must move to reach a target. The obtained measures of movement times across combinations of size and distance are modeled with Fitts's law, $MT = a + b \times \log_2(D/W + 1)$, where D is the distance moved and W is the width of the target.

In point-and-click interfaces the user may have knowledge or expectations about a target's size and location that aid selection; sometimes the user knows nothing about the target and has to rely solely on visual scanning for identifying the target. The difference between these situations may be illustrated by having to select frequently used menu items as opposed to rarely used ones or having to select an object that resides in a known location (e.g., the trash can icon) as opposed to an object that was recently added to the desktop. Studies employing the Fitts's law paradigm typically do not differentiate these situations, nor attempt to study their difference. Also, established test tasks for studying pointing (e.g., ISO 9241, 2000) do not differentiate these situations. All is well if advance knowledge of the location of a target does not affect how users perform pointing operations, how fast they do so, or the relative benefit of pointing techniques or devices. If, however, advance knowledge affects any of these parameters then current conclusions about pointing techniques and devices may apply only to some activities in point-and-click interfaces.

The present paper investigates how knowledge of target location affects pointing movements and performance in a comparison of two pointing devices, namely mouse and touchpad. We do so by introducing a variant of the precuing technique (Rosenbaum, 1980, 1983), which conveys different information to users about targets prior to their initiation of a pointing trial. We use the technique to create targets for which users know the location and targets that require visual scanning and preclude advance movement planning. This allows us to characterize how precuing changes performance and how the kinematics of pointing movements are affected by precuing; in particular we show how precuing influences pointing differently for mouse and touchpad. Whereas many studies have used the precuing technique (e.g., Bock & Arnold, 1992; Rosenbaum, 1980; Schellekens, Huizing, & Kalverboer, 1986), we are unaware of previous studies that use it for comparing pointing techniques or devices. Thus, our study complements previous studies of the submovement structure of pointing with mouse and touchpad (e.g., Dillen, Phillips, & Meehan, 2005;

Hertzum & Hornbæk, 2010; Walker, Philbin, & Fisk, 1997). On the basis of our results we discuss how typical evaluations of pointing techniques and devices handle precuing, and how the design of point-and-click interfaces may be informed by our findings on the effects of precuing.

2 Method

To empirically investigate the effect of target precuing during pointing movements, we conducted an experiment with four within-group factors: target precuing, pointing device, distance to target, and target size. The experiment also had participant age as a between-group factor. We have analyzed the age effects on pointing performance in a previous article (Hertzum & Hornbæk, 2010) and will only briefly consider them in this study. Therefore, the description of the experimental method that follows resembles that of our previous article.

2.1 Participants

The 36 experimental participants (18 females, 18 males) were between 12 and 69 years of age with an average of 34.75 years (*SD* = 21.17). All participants were right-handed and had normal or corrected-to-normal vision. Table 1 summarizes participants' experience using computers. All participants had experience using both mouse and touchpad. Furthermore, all participants had used computers for years and spent hours a week using computers, particularly for online activities. None of the participants were information technology (IT) students, none had an IT education, and none worked as IT professionals.

The participants formed three age groups of 12 participants: *young*, who were between 12 and 14 years of age with an average of 12.83; *adult*, who were between 25 and 33 years of age with an average of 28.75; and *elderly*, who were between 61 and 69 years of age with an average of 62.67. There were no differences between age groups in participants' ratings of their experience using mouse and touchpad, Fs(2, 34) = 1.53, 2.12, respectively (both ps > 0.1).

2.2 Tasks

In the experimental tasks eight objects were arranged in a circle around a centre object, and participants were required to alternate between selecting the centre object and one of the eight surrounding objects (see top left of Figure 1). The target that the participant should select next was highlighted in red while the other objects were light blue, all on a black background. When the current target had been selected it returned to light blue, and the next target became red. The first target in every task was the centre object. Its selection marked the start of the task. The task continued with the selection of one of the eight objects around the centre object. Participants had no advance knowledge of which of the eight surrounding objects to select because the order in which they became targets was randomized. In contrast, the selections of the centre object after having selected one of the eight objects surrounding it could be predicted from the alternating structure of the task. Each selection of the centre object entailed a movement in the direction opposite to the direction of the preceding selection of one of the eight surrounding objects. However, the reverse directions occurred during another pair of selections and movement directions were, thus, the same for precued and non-precued targets.

Our reasons for choosing this task were fourfold. First, we intended to study tasks that were demanding in motor and visual abilities but make low demands for mental activity, and the selected task appeared to be representative of such tasks. Second, the task involved movement in multiple directions and thereby resembled real-world conditions in which objects are located on a two-dimensional screen. Third, the task has previously been used for evaluating pointing devices. In studies of the submovement structure of cursor trajectories (e.g., Hwang, Keates, Langdon, & Clarkson, 2005; Moyle & Cockburn, 2005; Phillips & Triggs, 2001) it is more widely used than the multi-directional tapping test (ISO 9241, 2000). Fourth, the task served as an instance of target precuing (Rosenbaum, 1980, 1983), in that some of the targets occurred in the same location and consequently in a specific direction from the previous target. In addition, the task could be systematically varied on three dimensions expected to influence performance:

Target precuing (two levels). Precued targets were the selections of the centre object. These targets were precued by the fixed location of the centre object and the systematic manner in which they were to be selected (every second selection). Non-precued targets were the selections of the objects surrounding the centre object. Contrary to Fitts's law, which does not include target precuing, we expected that target precuing would affect target selection time.

Distance to target (three levels). The distance from one target to the next was the radius of the circle formed by the eight objects. The radius of the circle was 70 pixels (small), 175 pixels (medium), or 350 pixels (large). The large circle occupied the full height of the screen. According to Fitts's law, target selection time increases with increasing distance to targets.

Target size (two levels). Small targets had a diameter of 6 pixels, and large targets had a diameter of 21 pixels. According to Fitts's law, target selection time increases with decreasing target size.

2.3 Design

The experiment employed a mixed factorial design where participants were divided into age groups and all participants used both mouse and touchpad to complete two blocks of six tasks. Half of the participants in each age group used the mouse for the first half of the session and the touchpad for the second half of the session. The other half of the participants used the touchpad first, then the mouse. The order of the six tasks in a block was determined using one balanced Latin square for the six participants in an age group who started with the mouse and another for the six participants who started with the touchpad. A new pair of Latin squares was used for each block. Each task consisted of 32 trials and covered one level of distance to target, one level of target size, and both levels of target precuing. The trials in a task alternated between precued and non-precued targets. In sum, 36 participants, distributed onto 3 age groups (young, adult, elderly) performed:

2 pointing devices (mouse, touchpad) ×

2 blocks ×

3 distances to target (70, 175, and 350 pixels) ×

2 target sizes (6 and 21 pixels) ×

2 target precuings (precued, non-precued) ×

16 repetitions =

768 trials per participant.

2.4 Procedure

Each participant was run in an individual session, lasting an average of 44 minutes. After a brief presentation of the experiment, participants filled out a background questionnaire (see Table 1 for questions). Next, participants tried the experimental software for an average of three minutes on some training tasks. To support the use of the touchpad participants were offered a hand rest, which 19 of them used. Participants were instructed to work as quickly as possible, while maintaining high accuracy. They were also instructed to use only their right hand (i.e., their dominant hand) for performing the tasks.

Participants first completed two blocks of six tasks with one pointing device. A task was a consecutive sequence of trials with the next target appearing as soon as the previous target had been correctly selected. Participants could not proceed until the correct target had been selected. After each task participants could rest for a moment before they performed the next task. After completing the two blocks of tasks with one pointing device, participants completed two similar blocks of six tasks with the other pointing device.

The experimental sessions were conducted on a 1.86 GHz HP laptop with a wired mouse, a built-in 68mm × 39mm Synaptics touchpad, and a 15-inch screen with a resolution of 1024×768 pixels. The mouse had two buttons and a wheel but only the left button was used during the experiment. Touchpad selections could be made by tapping the surface of the touchpad or clicking the leftmost of the two buttons below the touchpad. The control:display gain was set at the middle value in Windows XP. A test application presented the tasks to participants and logged their input. In addition to logging object selections (clicks), the cursor position was logged every 15.6 ms.

2.5 Dependent measures

We measured error rate, trial completion time, and submovements.

Error rate was measured as the percentage of trials in a task for which participants missed a target by clicking one or several times in an empty part of the screen or on a wrong object.

Trial completion time was measured from the selection of one target to the selection of the next target. Trial completion time was further divided into reaction time, movement time, and selection time. Reaction time was defined as the interval from the start of a trial to the cursor had moved more than one pixel away from its initial position. Selection time was defined as the interval from the cursor entered the target for the last time until the end of the trial. Movement time was the interval between reaction time and selection time.

Submovements were defined on the basis of the speed and acceleration profiles of cursor movements (for an illustration, see Figure 1). The rationale for doing submovement analysis was that it may help characterize the consequences of target precuing. Using the NER and NERD digital filters (Kaiser & Reed, 1977, 1978), we first smoothed the logged cursor positions to reduce effects of friction and hand tremor and then differentiated them twice to get the speed and acceleration of the cursor at each point in time. We used filters with a 0-7 Hz pass band, a 7-9 Hz tolerance, and a stop band that ranged from 9 Hz upward. These filter settings are similar to those used by Ketcham et al. (2002) and the final filter used by Meyer et al. (1988). As in Walker et al. (1997), the first submovement of each trial was considered to begin when cursor speed exceeded 75 pixels/second. Subsequent submovements were considered to start immediately after the end of the prior submovement. A submovement ended when (1) speed reached zero or (2) acceleration changed signs from negative to positive indicating a relative minimum in speed (Walker et al., 1997). For a relative speed minimum to mark the end of a submovement we followed Hwang et al. (2005) by further requiring that the minimum in speed at the end of the submovement was less than 75% of the peak speed within the submovement. This ensured an actual slowdown in speed prior to the following speedup. From Hwang et al. (2005) we also adopted the criterion that a submovement had to be at least 100ms long. For each submovement we recorded its duration, endpoint, peak speed, and the length of the cursor trajectory.

3 Results

We analyzed the data using analysis of variance (ANOVA) and linear regression. Before the analyses, we removed 406 (1.5%) outlier trials, which were more than three inter-quartile ranges above the upper quartile in trial completion time.

3.1 Learning effects

For the 27242 non-outlier trials we found no difference in error rate between the first and the second block performed with a pointing device, Fs(1, 35) = 0.03 and 1.09 (both ps > 0.3) for mouse and touchpad, respectively. For the 24497 non-outlier, non-error trials, there were significant main effects of block on trial completion time for the mouse, $F(1, 35) = 11.29$, $p < 0.01$, and the touchpad, $F(1, 35) = 6.79$, $p < 0.05$. With both pointing devices participants were faster during the second block. To avoid that learning effects confound our results we use only the data from the second block in the remainder of our analysis. This further ensures that we analyze only trials for which participants have understood the precuing of the centre object.

3.2 Error rates

Table 2 shows error rates for the 13650 non-outlier trials in the second block. Before conducting the statistical analysis, the average accuracy of a task was arcsine transformed because percentage values cannot be assumed normally distributed (Fleiss, 1981). We found no main effect of target precuing on error rates, $F(1, 35) = 0.06$, $p = 0.8$, and no interactions between target precuing and any of pointing device, $F(1, 35) = 2.80$, $p = 0.1$, target distance, $F(2, 34) = 0.17$, $p = 0.8$, and target size, $F(1, 35) = 0.20$, $p = 0.7$.

3.3 Trial completion times

Table 3 shows trial completion times for the 12338 non-outlier, non-error trials in the second block. There was a significant main effect of target precuing, $F(1, 35) = 162.00$, $p < 0.001$, with shorter trial completion times for precued than non-precued targets. In addition, we found a significant interaction between target precuing and target distance, $F(2, 34) = 6.15$, $p < 0.01$. The difference in average trial completion time between precued and non-precued targets was longer for the large target distance (218ms) than for the small and medium target distances (158ms and 142ms, respectively). We also found a significant interaction between target precuing and target size, $F(1, 35) = 6.37$, $p < 0.05$. The difference in average trial completion time between precued and non-precued targets was larger for small targets (204ms) than large targets (155ms). The interaction between target precuing and pointing device approached significance, $F(1, 35) = 4.12$, $p = 0.05$, suggesting that the difference in average trial completion time between precued and non-precued targets may be larger for the mouse (194ms) than the touchpad (152ms).

3.4 Reaction time, movement time, and selection time

To analyze trial completion time further, we divided it into reaction time, movement time, and selection time, see Table 4.

For reaction time, there was a significant main effect of target precuing, $F(1, 35) = 116.99$, $p < 0.001$, with shorter reaction times for precued than non-precued targets. We found a significant interaction between target precuing and pointing device, $F(1, 35) = 7.77$, $p < 0.01$, with a larger difference in average reaction times between precued and non-precued targets for the touchpad (331ms vs 425ms) than the mouse (68ms vs 128ms). Another significant interaction was between target precuing and target distance, $F(2, 34) = 8.66$, $p < 0.01$, with a still larger difference in average reaction times between precued and non-precued targets as target distances increased from small (185ms vs 249ms) over medium (198ms vs 272ms) to large (216ms vs 308ms). We also found a significant interaction between target precuing and target size, $F(1, 35) = 5.36$, $p < 0.05$, with a larger difference in average reaction times between precued and non-precued targets for small (229ms vs 317ms) than large (171ms vs 236ms) targets.

For movement time, there was a significant main effect of target precuing, $F(1, 35) = 80.61$, $p < 0.001$, with shorter movement times for precued than non-precued targets. In addition, there was a significant interaction between target precuing and pointing device, $F(1, 35) = 12.94$, $p < 0.01$, with a larger difference in average movement times between precued and non-precued targets for the mouse (705ms vs 845ms) than the touchpad (1045ms vs 1122ms). There was also a significant interaction between target precuing and target distance, $F(2, 34) = 4.97$, $p < 0.05$, with a larger difference in average movement times between precued and non-precued targets for large (1080ms vs 1222ms) target distances than for small (653ms vs 756ms) and medium (892ms vs 973ms) target distances. We found no interaction between target precuing and target size, $F(1, 35) = 1.25$, $p = 0.3$.

For selection time, we found no main effect of target precuing, $F(1, 35) = 0.07$, $p = 0.8$. There was, however, a significant, but small, interaction between target precuing and target size, $F(1, 35) = 4.45$, $p < 0.05$, with a larger difference in average selection times between large and small targets for non-precued (573ms vs 677ms) than precued (582ms vs 671ms) targets. There was no interaction between target precuing and either pointing device or target distance (both *p*s > 0.2).

3.5 Submovements

Submovements were analyzed for the 12338 non-outlier, non-error trials in the second block. A multivariate analysis of the eight submovement measures in Table 5 showed a significant main effect of target precuing, Wilks's $\lambda = 0.12$, $F(8, 26) = 23.89$, $p < 0.001$, and significant interactions between target precuing and all three of pointing device, Wilks's $\lambda = 0.39$, $F(8, 26) = 5.09$, $p < 0.001$, target distance, Wilks's $\lambda = 0.13$, $F(16, 18) = 7.50$, $p < 0.001$, and target size, Wilks's $\lambda = 0.53$, $F(8, 26) = 2.92$, $p < 0.05$. With the experiment-wide error thus protected we analyzed the individual submovement measures.

For the number of submovements in a trial we found a significant main effect of target precuing, $F(1, 35) = 52.15$, $p < 0.001$, with fewer submovements for precued than non-precued targets. There were significant interactions between target precuing and all three of pointing device, $F(1, 35) = 6.22$, $p < 0.05$, target distance, $F(2, 34) = 8.44$, $p < 0.01$, and target size, $F(1, 35) = 4.71$, $p < 0.05$. These interactions showed a larger difference in the number of submovements between precued and non-precued targets (a) for the mouse (4.65 vs 5.17) than the touchpad (7.77 vs 8.06), (b) for large (7.08 vs 7.70) than for small (5.29 vs 5.56) and medium (6.25 vs 6.59) target distances, and (c) for small (7.34 vs 7.82) than large (5.08 vs 5.41) targets.

For the length of the cursor trajectory in percent of the inter-target distance we found a significant main effect of target precuing, $F(1, 35) = 91.93$, $p < 0.001$, with shorter cursor trajectories for precued than non-precued targets. There was also a significant interaction between target precuing and pointing device, $F(1, 35) = 23.38$, $p < 0.001$, with a larger difference in trajectory length between the mouse and the touchpad for precued (128% vs 149%) than non-precued (164% vs 165%) targets. There was no interaction between target precuing and either target distance or target size (both *p*s > 0.06).

For cursor speed during a trial we found a significant main effect of target precuing, $F(1, 35) = 14.71$, $p < 0.001$, with lower cursor speed for precued than non-precued targets. We also found a significant interaction between target precuing and pointing device, $F(1, 35) = 16.27$, $p < 0.001$, with a larger difference in cursor speed between precued and non-precued targets for the mouse (213 pixels/s vs 230 pixels/s) than the touchpad (138 pixels/s vs 139 pixels/s). There was no interaction between target precuing and either target distance or target size (both *p*s > 0.1).

For the submovement during which cursor speed peaked there was a significant main effect of target precuing, $F(1, 35) = 124.76$, $p < 0.001$, with peak speed reached during an earlier submovement for precued than non-precued targets. There was a significant interaction between target precuing and pointing device, $F(1, 35) = 21.87$, $p < 0.001$, with a larger difference in the number of the peak-speed submovement between precued and non-precued targets for the mouse (1.18 vs 1.55) than the touchpad (1.35 vs 1.52). We also found a significant interaction between target precuing and target distance, $F(2, 34) = 7.59$, $p < 0.01$, with a smaller difference in the number of the peak-speed submovement between precued and non-precued targets for small (1.19 vs 1.41) and medium (1.22 vs 1.46) than large (1.38 vs 1.74) target distances. There was no interaction between target precuing and target size, $F(1, 35) = 1.00$, $p = 0.3$.

For peak cursor speed we found a significant main effect of target precuing, $F(1, 35) = 69.17$, $p < 0.001$, with lower peak speed for precued than non-precued targets. There was also a significant interaction between target precuing and target distance, $F(2, 34) = 23.03$, $p < 0.001$, with a progressively larger difference in peak speed between precued and non-precued targets for small (547 pixels/s vs 628 pixels/s) over medium (1294 pixels/s vs 1453 pixels/s) to large (2454 pixels/s vs 2728 pixels/s) target distances. There was no interaction between target precuing and either pointing device or target size (both *p*s > 0.1).

For the submovement during which the cursor moved the longest we found a significant main effect of target precuing, $F(1, 35) = 106.36$, $p < 0.001$, with the longest cursor trajectory occurring in an earlier submovement for precued than non-precued targets. There was a significant interaction between target precuing and pointing device, $F(1, 35) = 17.55$, $p < 0.001$, with a larger difference in the number of the longest submovement between precued and non-precued targets for the mouse (1.17 vs 1.55) than the touchpad (1.33 vs 1.50). We also found a significant interaction between target precuing and target distance, $F(2, 34) = 9.77$, $p < 0.001$, with a smaller difference in the number of the longest submovement between precued and non-precued targets for small (1.17 vs 1.39) and medium (1.21 vs 1.44) than large (1.37 vs 1.74) target distances. There was no interaction between target precuing and target size, $F(1, 35) = 3.29$, $p = 0.08$.

For the length of the longest submovement in percent of the inter-target distance there was a significant main effect of target precuing, $F(1, 35) = 87.53$, $p < 0.001$, with a smaller part of the inter-target distance covered by the longest submovement for precued than non-precued targets. Notably, the longest submovement exceeded the inter-target distance for non-precued targets. We found a significant interaction between target precuing and pointing device, $F(1, 35) = 17.40$, $p < 0.001$, with a larger difference in the length of the longest submovement between precued and non-precued targets for the mouse (91% vs 106%) than the touchpad (93% vs 99%). There was a significant interaction between target precuing and target distance, $F(2, 34) = 6.58$, $p < 0.01$, with a progressively smaller difference in the length of the longest submovement between precued and non-precued targets for small (92% vs 106%) over medium (93% vs 103%) to large (90% vs 98%) target distances. There was no interaction between target precuing and target size, $F(1, 35) = 0.58$, $p = 0.5$.

For the distance left from the end point of the longest submovement to the centre of the target, in percent of the inter-target distance, there was a significant main effect of target precuing, $F(1, 35) = 32.90$, $p < 0.001$, with a shorter distance remaining for precued than non-precued targets. We found no significant interactions between target precuing and any of pointing device, $F(1, 35) = 2.76$, $p = 0.1$, target distance, $F(2, 34) = 0.56$, $p = 0.6$, and target size, $F(1, 35) = 0.02$, $p = 0.9$.

3.6 Modelling by Fitts's law

The trial completion times for the 12338 non-outlier, non-error trials in the second block were modelled using Fitts's law. Figure 2 shows the resulting regression lines, which were based on the average trial completion times for each combination of target precuing, pointing device, and index of difficulty. To quantify the effect of target precuing we made a composite regression model by adding target precuing to Fitts's law. Because the preceding analysis shows that target precuing had a main effect on trial completion time and also interacted with the index of difficulty, we included target precuing in the composite model both as an independent term and multiplied with the index of difficulty, see Table 6. The composite model was significant for both mouse and touchpad, $F\text{s}(3, 8) = 40.57, 34.53$, respectively (both $p\text{s} < 0.001$). With R^2 values of 94% (mouse) and 93% (touchpad) the composite model explained trial completion time well and, particularly for the mouse, better than a Fitts model including precued as well as non-precued targets (Table 6).

For the mouse the composite model shows that as the index of difficulty increased from 2 to 6 the overhead of non-precued compared to precued targets increased from 106ms (15%) to 282ms (16%). Thus, the overhead was proportional to the increase in the index of difficulty. For the touchpad the overhead of non-precued compared to precued targets changed from 151ms (10%) to 139ms (5%) as the index of difficulty increased from 2 to 6. Thus, the overhead was near constant and largely unaffected by the change in the index of difficulty.

3.7 Effects of age

Target precuing was affected surprisingly little by age group. We found no interactions between target precuing and age group for any of error rate, trial completion time, reaction time, movement time, selection time, and the eight submovement measures (all $p\text{s} > 0.08$). Age group was, however, involved in some second-order interactions. Most notably, there were significant second-order interactions between target precuing, age group, and target size for trial completion time, number of submovements, submovement during which cursor speed peaked, and submovement during which the cursor moved the longest, $F\text{s}(2, 34) = 4.84, 6.12, 8.56, 13.09$, respectively (all $p\text{s} < 0.05$). These second-order interactions all indicated that for the elderly participants, but not for the young and adult participants, the difference in performance between precued and non-precued targets was larger for small than large targets. For example, the difference in average trial completion time between precued and non-precued targets was larger for small than large targets, due to the elderly participants who experienced a drop from 238ms to 105ms, whereas young and adult participants experienced drops in the range 175-190ms for both small and large targets.

4 Discussion

Table 7 summarizes the results of our analyses. For as many as 11 of the 13 analyzed measures we find a main effect of target precuing. Precuing affects trial completion time, reaction time, movement time, and all eight submovement measures; the only measures unaffected by precuing are error rate and selection time. In addition, a large number of interactions show that pointing device, target distance, and target size, but not age group, differentially affect how precuing changes the pointing movements. To facilitate interpretation of the interactions, Table 7 also shows the main effects of pointing device, target distance, target size, and age group; more detail about these effects can be found in Hertzum and Hornbæk (2010).

4.1 Target precuing and movement preparations

The non-precued targets became known to participants at the onset of the pointing trials. Thus, the effects of precuing must be due to different possibilities for mental and motor preparations prior to this onset of the pointing movement. The multiple consequences of making it impossible for participants to prepare show the extent of such preparations in the execution of pointing movements. First, the consequences extend beyond the initial phase of the pointing movements and, instead, affect the movements until the cursor has been positioned over the target. For example, peak speed is reached during a later submovement and, similarly, the longest submovement occurs later. The longest and fastest submovement is generally considered to be distance-covering and to bring the cursor close to the target, whereas the remaining submovements are corrective and aimed at attaining the precision necessary to position the cursor over the target (Balakrishnan, 2004; Meyer et al., 1988). For non-precued targets we find that the distance from the end point of the longest submovement to the target is longer than for precued targets, indicating that both the distance-covering part and the following corrective part of the pointing movement are affected by target precuing.

Second, the submovement measures show that with the preparations enabled by precued targets the movements become more efficient and precise. For example, the number of submovements is smaller and the length of the cursor trajectory in percent of the inter-target distance is shorter. This increase in precision is consistent with previous work, for example Olivier and Bard (2000) find that the angular error of movements at the point of peak speed is lower for precued than non-precued targets. Notably, the increase in movement precision co-occurs with shorter trial completion times and is, thus, not the result of a speed/accuracy trade-off. Rather, the movement preparations enabled by precuing must be performed, partially, in parallel with the other processes involved in making pointing movements. Such partial parallelism in the mental preparation and planning of pointing movements accords with widely accepted accounts of pointing (Fitts & Peterson, 1964; Guiard, 1997). The difference in movement precision also suggests that for non-precued targets participants tend to initiate their pointing movements on the basis of incomplete preparations rather than postpone movement initiation until preparations have been completed.

Third, participants appear to compensate for their inability to prepare their non-precued pointing movements by making faster initial submovements. The main indication of this is that peak speed is higher than for precued targets. This result discords with previous studies (Olivier & Bard, 2000; Schellekens et al., 1986), which find higher peak speed for precued targets and argue that this indicates better movement planning for these targets. As discussed above, the higher peak speed for our participants' non-precued targets is accompanied by increased imprecision and decreased overall efficiency. For example, the longest submovement exceeds the inter-target distance and ends further away from the target than for precued targets, increasing the need for corrective submovements. In accordance with previous studies (Anson, Hyland, Kotter, & Wickens, 2000; Bock & Arnold, 1992), these additional results show that the participants do not succeed in compensating for the absence of prior-to-onset preparations associated with non-precued targets.

Fourth, the effects of precuing are similar for young, adult, and elderly participants. This is particularly noteworthy because there are multiple main effects of precuing and of participant age, but none of these effects interact (Table 7). A complete absence of interactions between precuing and age has also been reported for differently aged children, suggesting that at seven years of age children are able to make full use of precues in their movement preparations (Olivier & Bard, 2000). Our study shows that the capability to use precues in the planning and execution of pointing movements does not deteriorate in elderly participants.

4.2 Device differences

An important result of this study is that precuing affects the mouse and touchpad differently. For as much as eight of the 11 measures for which we find an effect of precuing we also find an interaction between precuing and pointing device (Table 7). The difference between precued and non-precued targets is larger with the mouse than the touchpad for all eight interactions except the one for reaction time, indicating that with the mouse users are better able to benefit from precuing. A possible explanation of this may be that to benefit from precuing users need to perform additional mental processes in parallel with those they are already performing to operate the pointing device. Under the general assumption that such processing resources are limited there will be fewer resources available to benefit from precuing when using a pointing device that is more taxing. Multiple studies show that the touchpad is more difficult and demanding to operate than the mouse (Epps, 1986; Hertzum & Hornbæk, 2010).

The regression models show that for the mouse, and marginally for the touchpad, extending Fitts' law with target precuing increases the amount of variation in trial completion time explained by the model (Table 6). With the mouse the benefit of precued over non-precued targets increases proportionally to the index of difficulty. Thus, for the mouse the effect of precuing is not solely about having resources available, because more resources are available during the low index-of-difficulty tasks for which the effect of precuing is smallest. It appears that the trial completion time for the tasks with the lowest index-of-difficulty values is, instead, determined mainly by factors other than those benefitting from precuing. However, as the tasks become more difficult, movement planning becomes more important to efficient performance and the benefit of precuing increases. With the touchpad the benefit of precued over non-precued targets is largely constant over the range of index-of-difficulty values, suggesting that resource depletion constrains the effect of precuing.

4.3 Types of target precues

Precuing may reveal different properties of a target. In this study targets are non-precued in the sense that the direction of movement is unknown until the onset of the pointing trial, whereas the distance to the target and the target size are constant within each task and known for precued as well as non-precued targets. Previous studies show that reaction time shortens when the number of precued properties increase (Olivier & Bard, 2000), that a directional precue in the absence of a distance precue shortens reaction time more than a distance precue in the absence of a directional precue (Anson et al., 2000), and that precuing of direction and distance shortens reaction time more for long than short movements (Schellekens et al., 1986). Effects of precuing on movement time are less common. Olivier and Bard (2000) find that a directional precue does not reduce movement time unless accompanied by a distance precue. These previous studies suggest that the continual presence of distance and size precues in our study may be a necessary enabler for some of the effects we find of directional precuing. Conversely, our study shows that even when the target has already been narrowed down to a small number of visible same-size, same-distance candidates, substantial performance improvements result from also knowing the direction, that is the exact target location, prior to movement onset.

In pointing movements an initial distance-covering submovement is followed by corrective submovements to acquire the target, indicating a shift in the planning and execution of such movements from target distance toward target size (Meyer et al., 1988; Welford, 1977). In much the same way, direction appears to precede distance in that unexpected changes in direction prolong reaction times more than changes in distance (Larish & Frekany, 1985), possibly because direction is mainly controlled through proactive planning and distance more through ongoing regulation (Olivier & Bard, 2000). With respect to target size studies of target expansion show that users benefit from target expansion even if targets do not begin to expand until the cursor has travelled 90% of the distance to the target (McGuffin & Balakrishnan, 2005), and even if target expansion does not always occur and thus cannot be assumed in planning the pointing movement (Zhai, Conversy, Beaudouin-Lafon, & Guiard, 2003). For tasks with a high index of difficulty, users of expanding targets perform approximately at a level corresponding to targets with a constant size equal to the fully expanded targets (McGuffin & Balakrishnan, 2005). That is, users take almost full advantage of the target expansion when it unpredictably occurs. This indicates that precuing of target size has little impact on pointing performance, which depends mainly on the final, possibly expanded, target size rather than on the initial, possibly precued, target size.

Whereas direction, distance and size precues reveal spatial properties of a target, precues may also be temporal and thereby reveal when a target appears. Temporal precues have been found to increase alertness, spatial precues to improve orienting, which is the selective allocation of attention to a part of the visual field (Fernandez-Duque & Posner, 1997; Petersen & Posner, 2012). In our study there is some temporal information in the rhythmic alternation between selecting the centre target and one of the surrounding targets but this temporal information is equally present for precued and non-precued targets. Thus, the effect of our precued targets is presumably that they improve orienting by directing attention to the target earlier than this can happen for the non-precued targets. Posner, Snyder, and Davidson (1980) find that a spatial precue on each trial has a stronger effect than when a probable target position is held constant for a block of trials, suggesting that the permanent location of the centre target in our study is a relatively weak precue. Our results show that even this weak precue affects pointing movements appreciably. Previous studies also show that spatial precues improve performance to the same degree irrespective of the user's level of alertness (Fernandez-Duque & Posner, 1997). This finding provides a basis for contending that our results are not an artefact of the experimental setting, in which participants may be more alert to the appearance of pointing targets than during their day-to-day pointing movements.

4.4 Implications

The results of our study have several implications for research. First, precuing affects results and it is, therefore, important to distinguish between results obtained for precued and non-precued targets. For example, the difference in the slope of the Fitts models for pointing with the mouse at precued and non-precued targets is 44 ms/bit (Table 6). This difference is similar in magnitude to several of the slope differences between pointing devices in MacKenzie's (1992) review of six pointing studies, including a 50 ms/bit difference between joystick and trackball, a 45 ms/bit difference between trackball and mouse, a 42 ms/bit difference between mouse and touchpad, and a 15 ms/bit difference between touchpad and joystick. If some of the reviewed studies involve precued targets while others involve non-precued targets, precuing rather than device may explain the differences.

Second, precuing is typically an implicit and easily overlooked aspect of the tasks used for evaluating pointing devices. This complicates or invalidates cross-study comparisons. In the one-direction tapping test (ISO 9241, 2000), targets are precued in that two targets are present and users alternate between clicking at one and the other. In the multi-directional tapping test (ISO 9241, 2000), targets are quasi-precued in that the next target is always the diametrically opposite in a circular layout of targets. The targets are not visually precued because the next target is not visually indicated until the previous target has been selected, but the target sequence is almost fully given by the repeated movements along the diameter of the circular layout and by the rhythmic to-and-fro movement this instils. In more random target layouts, which are used in many pointing-device evaluations (Blanch & Ortega, 2011), targets are typically not precued but, instead, indicated once the previous target has been selected. It would be valuable to develop a variant of the multi-directional tapping test with no precuing of target location.

Third, in this study precuing affects pointing devices differently. This result was unexpected and suggests that the choice of evaluation task may impact device comparisons significantly. Above we speculated on a likely interaction between precuing and how demanding a pointing device is to use, proposing that the benefits of precuing are greater for less demanding pointing devices than for more demanding pointing devices. It would be interesting to investigate this speculation further.

Fourth, the relation between visual precuing and motor precuing warrants further investigation. In our study participants alternated between clicking at non-precued targets laid out in a circle and at a centre target that was precued visually and by the motor information inherent in returning to the centre target. This way our precued targets are an instance of cyclical pointing, which Guiard (1997) argues should be considered the general case whereas its contrast, discrete pointing, is the exception. A separation of visual and motor precuing is, however, possible by studying precuing in the context of discrete pointing, in which the user performs individual pointing movements each separated by a break that prevents the rhythmic movements characteristic of cyclical pointing.

While the main purpose of the present study is not to generate design implications, four design ideas may be mentioned. First, precues should be provided whenever possible. Pop-up windows may, for example, draw a wireframe outline of the window and its buttons before revealing the window content. This simple technique will provide users with precues of the main pointing targets in the window while its content is loading. Hierarchical menus may benefit from expanding two levels of the menu structure in response to user selections, thereby revealing the submenu selected by the user and, at the same time, precuing the menu items that can be reached with the next selection. McGuffin et al. (2004) use such an expand-ahead scheme in a tree browser, expanding subfolders and their content as space allows. They argue that expand ahead may support users in content exploration; it may also support efficient pointing. Second, the large performance differences between precued and non-precued targets raises important design questions, such as how long before pointing movements the precue must be provided to annul the overhead incurred by non-precued targets and how accurately the precue must specify the direction and distance in order to be useful. Size precues need not be accurate (McGuffin & Balakrishnan, 2005; Zhai et al., 2003). Third, in the absence of precues about the direction or distance to a target the movement toward the target is less precise. This increases the uncertainty of any calculations that aim to use the initial part of a pointing movement to predict its intended direction or end point (e.g., Lank, Cheng, & Ruiz, 2007; Murata, 1998). It may be possible to improve predictions by utilizing information about whether the possible targets were precued or non-precued. With such information the prediction could, for example, adjust for our finding that the longest submovement tended to undershoot precued targets but slightly overshoot non-precued targets. Fourth, techniques that move targets, for example drag-and-pop (Baudisch et al., 2003) and fisheye menus (Bederson, 2000), destroy precues. For these techniques to be effective the advantage of moving the targets must exceed the overhead that comes with non-precued targets.

5 Conclusion

Users who select objects in point-and-click interfaces sometimes know features of those objects, such as their size or location. Earlier work on movement precuing has established a paradigm to study the effects of such knowledge. The present study has shown that the absence or presence of location precues affects multiple aspects of performance and movement kinematics, including the reaction time, the total time to complete a pointing operation, the number of submovements in the cursor trajectory, and the length of the cursor trajectory. The mechanism behind these results seems to be different possibilities for mental and motor preparation of the movements. For precued targets the preparations lead to more efficient and precise pointing movements than for non-precued targets. Target precuing also interacts with pointing device, distance to target, and target size, but not with user age. In particular, the benefit of precuing is larger for the mouse than the touchpad, suggesting that the movement preparations users are able to make on the basis of precues depend on how demanding the pointing device is to use. Our results identify a need for careful consideration of target precuing when conducting experimental evaluations of pointing techniques and when making comparisons across such evaluations.

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Table 1. Participants' experience using computers, $N = 36$ participants

Question	*Mean*	*Std. deviation*
Mouse experience (1: none – 9: very experienced)	7.11	1.35
Touchpad experience (1: none – 9: very experienced)	5.14	2.21
Years of computer use	10.24	5.71
Years of Internet use	7.60	3.38
Hours of computer use a week	20.93	14.27
Hours online a week	13.79	11.65

Table 2. Error rates in percent, $N = 13650$ non-outlier trials

		Precued targets		Non-precued targets	
		Mean	*Std. error*	*Mean*	*Std. error*
Pointing device					
	Mouse	8.3	0.9	8.2	1.0
	Touchpad	10.8	1.2	11.4	1.2
Target distance					
	70 pixels	8.8	1.0	9.2	1.1
	175 pixels	9.9	1.1	9.5	0.9
	350 pixels	10.1	1.0	10.6	1.0
Target size					
	6 pixels	13.5	1.4	14.1	1.3
	21 pixels	5.6	0.6	5.5	0.7
Overall		9.6	0.9	9.8	0.9

Table 3. Trial completion times in milliseconds, *N* = 12338 non-outlier, non-error trials

		Precued targets		Non-precued targets	
		Mean	*Std. error*	*Mean*	*Std. error*
Pointing device					
	Mouse	1199	25	1393	29
	Touchpad	2172	65	2324	66
Target distance **					
	70 pixels	1438	38	1596	40
	175 pixels	1702	44	1844	39
	350 pixels	1917	44	2135	51
Target size *					
	6 pixels	2017	50	2221	54
	21 pixels	1381	33	1536	35
Overall ***		1686	41	1858	42

* $p < 0.05$ (interaction effect), ** $p < 0.01$ (interaction effect), *** $p < 0.001$ (main effect)

Table 4. Reaction, movement, and selection times in milliseconds, $N = 12338$ non-outlier, non-error trials

		Precued targets		Non-precued targets	
		Mean	*Std. error*	*Mean*	*Std. error*
Reaction time	***	200	7	276	10
Movement time	***	875	24	984	29
Selection time		626	20	625	19

*** $p < 0.001$

Table 5. Submovement measures, $N = 12338$ non-outlier, non-error trials

		Precued targets		Non-precued targets	
		Mean	*Std. error*	*Mean*	*Std. error*
Number of submovements	***	6.21	0.14	6.62	0.16
Trajectory length (%) [a]	***	138	2.5	165	4.0
Trial speed (pixels/s)	***	176	3.8	185	5.0
Peak-speed submovement [b]	***	1.26	0.02	1.54	0.03
Peak speed (pixels/s)	***	1432	29	1603	39
Longest submovement [c]	***	1.25	0.02	1.52	0.03
Length of longest submovement (%) [d]	***	92	1.3	103	2.0
Distance left to target (%) [e]	***	25	0.5	28	0.6

[a] Length of cursor trajectory in percent of inter-target distance. [b] The submovement during which cursor speed peaked. [c] The submovement during which the cursor moved the longest. [d] Length of cursor trajectory during longest submovement in percent of inter-target distance. [e] Distance from endpoint of longest submovement to centre of target, in percent of inter-target distance.

*** $p < 0.001$

Table 6. Regression models of trial completion time

	Model	Included targets	Regression model [a]	R^2
Mouse				
	Fitts model	Precued	*Time* = 224 + 250×*ID*	93
	Fitts model	Non-precued	*Time* = 243 + 293×*ID*	93
	Fitts model	All	*Time* = 233 + 272×*ID*	86
	Composite model	All	*Time* = 224 + 18×*Precuing* + 250×*ID* + 44×*ID*×*Precuing*	94
Touchpad				
	Fitts model	Precued	*Time* = 756 + 358×*ID*	92
	Fitts model	Non-precued	*Time* = 913 + 355×*ID*	93
	Fitts model	All	*Time* = 835 + 357×*ID*	90
	Composite model	All	*Time* = 756 + 157×*Precuing* + 358×*ID* - 3×*ID*×*Precuing*	93

[a] *Time*: trial completion time in milliseconds; *ID*: index of difficulty, i.e. $\log_2$(Distance/Size + 1); *Precuing*: 0 – precued target, 1 – non-precued target

Table 7. Summary of significant effects

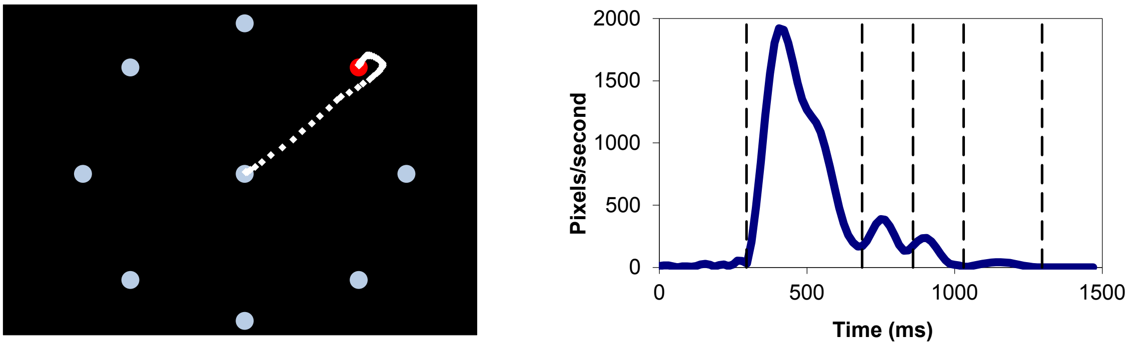
	Main effect of	First-order interactions between precuing and				Other main effects[f]			
	Precuing	Device	Distance	Size	Age	Device	Distance	Size	Age
Error rate						**		***	*
Trial completion time	***		**	*		***	***	***	***
Reaction time	***	**	**	*		***	***	***	***
Movement time	***	**	*			***	***	***	***
Selection time				*		***	**	***	***
Number of submovements	***	*	**	*		***	***	***	***
Trajectory length[a]	***	***				**	***	***	
Trial speed	***	***				***	***	***	***
Peak-speed submovement[b]	***	***	**				***	**	***
Peak speed	***		***			***	***		
Longest submovement[c]	***	***	***				***	**	***
Length of longest submovement[d]	***	***	**				***	***	
Distance left to target[e]	***					***	***	***	***

[a] Length of cursor trajectory in percent of inter-target distance. [b] The submovement during which cursor speed peaked. [c] The submovement during which the cursor moved the longest. [d] Length of cursor trajectory during longest submovement in percent of inter-target distance. [e] Distance from endpoint of longest submovement to centre of target, in percent of inter-target distance. [f] More detail about these effects is reported in Hertzum and Hornbæk (2010).

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

(a) Logged cursor positions

(c) Speed



(b) Distance from start

(d) Acceleration

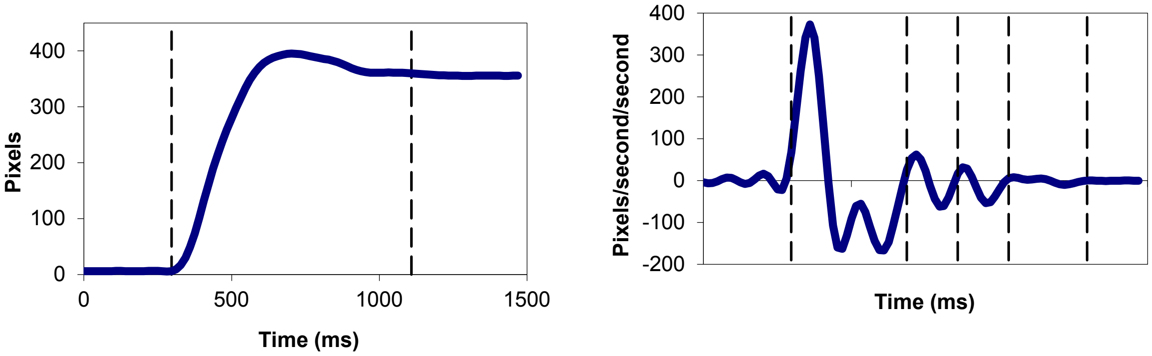


Figure 1. Example of participant pointing with the mouse: (a) logged cursor positions for movement across large distance to large target; (b) distance moved away from start, dashed lines indicating boundaries between reaction, movement, and selection times; (c) movement speed, dashed lines indicating submovement boundaries; (d) movement acceleration, dashed lines indicating submovement boundaries.

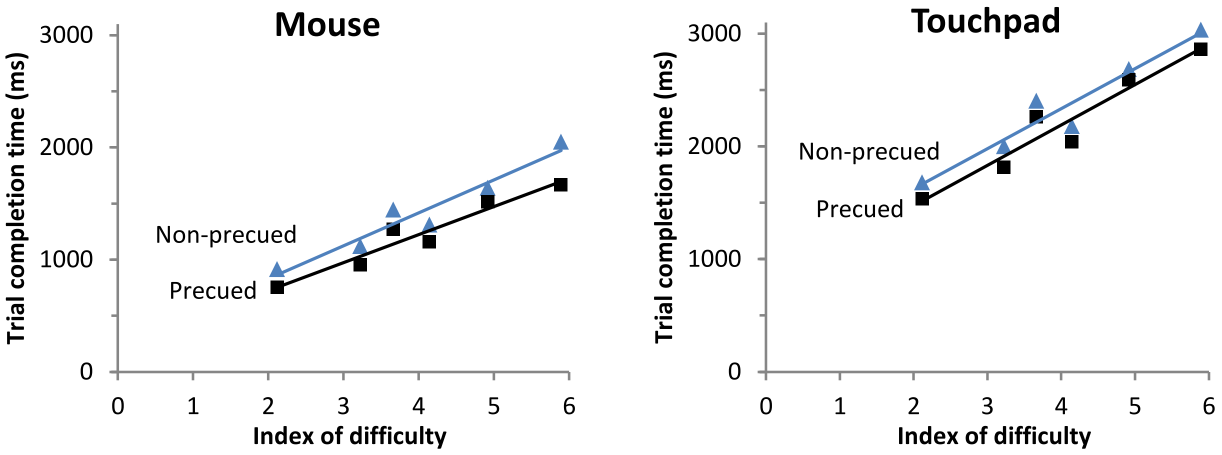


Figure 2. Regression lines for index of difficulty versus trial completion time