The Effects of Intended Use on Target Acquisition

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ABSTRACT
Fitts's Law has been used extensively in HCI to describe 2D targeting; however, the controlled tasks generally used neglect aspects of real-world pointing, including how the intended use of a target affects its acquisition. We studied aiming to a target in four tasks requiring varying precision after acquisition. Our results present the first evidence that the intended use of a target affects its acquisition in terms of movement time and motion kinematics for computer aiming. Important for researchers who model 2D targeting, our results also have particular impact for HCI research that uses motion kinematics.

Author Keywords
Pointing, Fitts's Law, motion kinematics, intention

ACM Classification Keywords
H5.2. Information Interfaces and Presentation: User Interfaces - *Interaction Styles; Input devices and strategies*.

General Terms
Human Factors.

INTRODUCTION
There has been a long history of using Fitts's Law [2,6] to describe pointing on a computer display and to build models of targeting in HCI. Researchers generally use controlled tasks of a single type that represent common activities in computer use (e.g., reciprocal tapping task, docking task) to study targeting and build performance models. As results from these controlled studies begin to influence the development of interaction techniques – such as endpoint prediction-based targeting assistance – we need to consider whether there are aspects of computer aiming that laboratory experiments do not adequately represent. For example, by studying only discrete aiming tasks, we do not consider how the intended use of a target (e.g., click, dock) affects its initial acquisition.

Previous studies in human motor control have shown that intended use of a grasped disk affects the wrist kinematics of the initial reach-to-grasp movement [8]. Tasks requiring greater precision after the acquisition produced different movement times and velocity profiles. It is possible that the intended use of a target affects pointing behavior in desktop settings, as many of our models of pointing on 2D displays are derived from research on 3D aiming in the real world.

We focus on one aspect of intention – what the user will do with a target after its acquisition. We call this intention as the user plans their aiming movement to a target with its intended use in mind. We tested the effects of target use in 2D aiming with a mouse, over four tasks (targeting, double targeting, flicking, and docking), and found that the intended use of a target affects the movement time and motion kinematics of the initial target acquisition. Our results are important for researchers who model aiming on a computer, and have particular impact for HCI research that uses kinematics (e.g., endpoint prediction), or that attempts to model aiming in real-world computer use.

RELATED WORK

Models of Targeting
Woodworth [13] investigated the speed-accuracy tradeoff in aiming movements, and proposed that aiming is comprised of two phases: an initial impulse toward the target, and a deceleration phase to home-in on the target. Fitts & Peterson [2] quantified the speed-accuracy tradeoff for *discrete* aiming movements in what is now known as Fitts's Law [6]. Fitts's Law has been adapted to model computer aiming [6]. The equation quantifies the difficulty of an aiming task (the index of difficulty, ID), and demonstrates that movement time (MT) can be correlated with ID and predicted with a regression equation.

$$(1) \quad ID = log_2\left(\frac{A}{W} + 1\right) \qquad (2) \quad MT = a + b(ID)$$

where A is the movement amplitude, W is the target width, and a and b are empirically-determined constants. There are various models of motor control for aiming movements, but the most successful one corresponds with Woodworth's two-phase model. The optimized initial impulse model [9] suggests that an initial ballistic movement is made towards the target, and if successful, then the task is accomplished. If not, a secondary movement is undertaken and this process repeats until the target is acquired. To optimize aiming movements under the constraints of the speed-accuracy tradeoff, movements consist of a high-velocity (ballistic) initial phase, and a series of slower, visually-guided, feedback-corrected movements (homing-in).

Motion Kinematics

MacKenzie et al. [5] examined the 3D velocity profiles of discrete aiming movements and showed that for movements of the same ID (i.e., same MT), the shape of the velocity profiles differed depending on A & W. The timing and magnitude of the peak velocity (ballistic phase) related to movement amplitude, while the proportion of time spent decelerating (homing-in phase) depended on target width. Walker reproduced the relationship between movement amplitude and peak velocity for 2D aiming with mice [12].

Kinematic measures have been used in HCI to describe differences between physical and virtual pointing [3] and to discriminate between aiming to different target shapes [11]. Velocity-based measures also have explanatory power for movement time differences. They have been used in HCI to explain the effects of sticky targets [7] and aiming across multiple displays [10]. Kinematic measures have also been used to predict the endpoint of a targeting motion [1, 4].

Motion Constraints

Marteniuk et al. [8] investigated 3D movement trajectories of the wrist for aiming under varying constraints, such as grasping a disk to either throw into a box or place in a tight-fitting well. They found that although the initial reach-to-grasp movement was the same, grasping a disk to place it into a tight-fitting well resulted in longer movement times, reflected in the lengthening of the deceleration phase. In addition, velocity just prior to grasp was higher for the throwing condition than the placing condition.

EXPERIMENT

We studied how the intended use of a target affects the motion time and kinematics of the initial targeting motion.

Experimental Setting and Protocol

Users performed a discrete aiming task [2] using a system implemented in Python on a 3.6 GHz WinXP machine, a 17-inch monitor (1280x1024 pixels), and a gaming-grade Logitech G5 optical mouse with a 2000 DPI resolution.

Task

Participants performed four different discrete aiming tasks. The initial aiming movement of each task (*subtask one*) was the same, but the tasks required different actions to be taken once the target was acquired (*subtask two*) (see Figure 1).

For the aiming subtask, participants were presented with a series of trials that first required them to select a grey start square and subsequently select a green target circle, which was presented as soon as the start square was clicked. When the cursor entered the circle, visual feedback was provided to the user by changing the colour of the circle to lighter green. Target circles were presented at three *target widths* (30, 60, and 120 pixels) and three *movement amplitudes* (150, 300, and 600 pixels), which combined to form five unique *IDs* (1.17, 1.81, 2.58, 3.46, 4.39 bits). As shown in Figure 1, the start square and target circle were always presented in a straight line along the center of the display. Descriptions of the action subtask for the four tasks follow.

Target Task: For the *target* task, users were instructed to click on a circular target when it appeared on the screen (subtask one). Once the initial target was acquired, participants returned to the start square for the next trial.

Dual Target Task: For the *dual target* task, both the primary target (green circle) and a secondary target (blue circle) were displayed. Participants were instructed to click on the primary target (subtask one) before clicking on the secondary target (subtask two). Secondary targets were presented in one of three directions (left, right, and top).

Flick Task: In the *flick* task, both the primary target and a 35-pixel green border were presented to participants at the beginning of the trial. Participants were instructed to flick the target towards the green border, which was presented in one of three directions (the left, right, or top edge). This task was intended to reflect the throwing task in [8].

Docking Task: The docking task (*dock*) required participants to first select the primary target, and then drag the target into a circular dock. The dock had a width that was 20 pixels larger than the width of the primary target, and was presented at one of three locations (left, right, and top). This task was intended to echo the fitting task in [8].

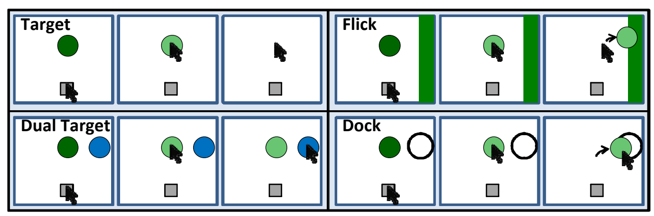

Figure 1. The four tasks. Frame 1- selecting the start square; Frame 2- the initial targeting movement (same for all tasks); Frame 3- the action to be taken with the acquired object.

The four tasks varied in the precision required in subtask two. Target and dual target were low-precision tasks; flick was medium-precision; and dock was a high-precision task.

Design

The experiment used a 4(*task*) by 3(*width*) by 3(*amplitude*) within-subjects full-factorial design. In addition, 3 targeting *directions* were presented for the *dual*, *flick*, and *dock* tasks. For each combination of factors, users completed 3 trial blocks (first block was training), resulting in 270 trials per participant. The order of trials within a task was random, while the order of the four tasks was fully counterbalanced.

Participants and Procedure

After filling in a consent form and demographic survey, participants were introduced to the four tasks, and were instructed to complete each trial as quickly as possible while remaining accurate. Forty-eight participants (22 female), aged 18-38 (mean 24) all used computers daily and were right-hand mouse users. The study took 20 minutes.

Data Analyses and Dependent Measures

All dependent measures focus on the initial aiming movement to the primary target (subtask one) and were determined from computer logs. Movement time (*MT*) was defined as the time from clicking on the start square until the primary target was selected. We logged errors of three types: *click errors*- when participants clicked outside of the primary target after selecting the start square; *exit errors*- when participants exited and re-entered the primary target prior to selection; *start errors*- when users moved off the start square after clicking, but before the target appeared.

Computer logs also recorded all of the mouse cursor x- and y- positions and accompanying timestamps. These were processed trial-by-trial in MATLAB and interpolated to create time-equidistant (120Hz) arrays. These arrays were differentiated to provide cursor velocity in both the x- and y- directions, then used to calculate velocity profiles, which were smoothed using a 25ms moving-average filter window. These profiles were used to calculate the motion kinematics measures including: peak velocity (pkV), time to peak velocity (tPkV), percent of time after peak velocity (%afterPkV), and click velocity (clickVel) for each trial. Click velocity was calculated as the mean velocity over the 33ms prior to selecting the primary target.

Outlier trials that took longer than three standard deviations above the mean (calculated over all trials) to complete were removed (177/12960 trials, 1.4%). We also removed trials that contained start errors (324) and click errors (360) from further analyses (684 trials, 5.3%). Due to large numbers of start errors leaving empty cells in the experiment design, three participants were removed from subsequent analyses.

After averaging over repeated trials, a one-way ANOVA tested whether *direction* in subtask two affected the initial aiming movement for flick, dock, and dual target. No difference was found (p=.851); these trials were aggregated. We conducted a RM-MANOVA on MT, PkV, tPkV, %afterPkV, ClickVel, and exit errors with ID (Equation 1) and task as factors, and with α=0.05. When the sphericity assumption was violated, the Huynh-Feldt method for adjusting the degrees of freedom was used. All pairwise comparisons used the Bonferroni correction with α=0.05.

Results

As expected, there were effects of ID on all measures (all $p<.001$, $.29<\eta^2<.94$). For MT, PkV, and tPkV, pairwise tests showed differences between each ID. For %afterPkV and clickVel, differences were found between each ID except for between the two smallest IDs. There were no interactions between ID and task on any of the measures except MT ($F_{9.2,403.0}=3.6$, $p<.001$, $\eta^2=.08$; all other p>.100). The interaction showed that there was no difference between the 2 smallest IDs for the target and dual tasks, but that all other levels of ID were different for all of the tasks.

Movement Time and Exit Errors

There was a significant effect of task on MT ($F_{2.8,120.9}=17.5$, $p<0.001$, $\eta^2=.28$). Pairwise comparisons showed that target and dual target were faster than flick or dock. See Figure 2.

There was no significant effect of task on exit error rates ($F_{3,132}=.62$, $p=.602$, $\eta^2=.01$). See Figure 2.

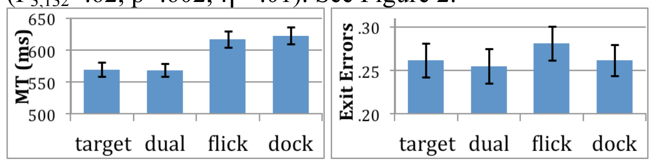

Figure 2. Means ± SE for movement time and exit errors.

Velocity-based Measures

There was a significant effect of task on PkV ($F_{3,132}=4.7$, $p=.004$, $\eta^2=.10$). Pairwise comparisons showed that flick had a higher PkV than target or dual target (see Figure 3).

There was a significant effect of task on clickVel ($F_{3,132}=14.9$, $p<.001$, $\eta^2=.25$). Pairwise comparisons showed that participants were moving faster just prior to click in target and dual target than flick or dock. See Figure 3.

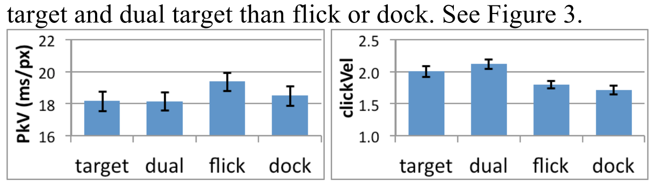

Figure 3. Means ± SE for peak velocity and click velocity.

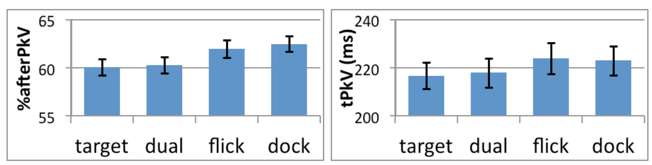

Figure 4. Means ± SE for time to peak velocity and % time after peak velocity.

There was a significant effect of task on %afterPkV ($F_{3,132}=3.8$, $p=.011$, $\eta^2=.08$). Pairwise comparisons showed that target and dual target had shorter deceleration phases than dock. See Figure 4. There was no significant effect of task on tPkV ($F_{2.7,117.5}=1.0$, $p=.382$, $\eta^2=.02$). See Figure 4.

DISCUSSION

Our results show that intended use of a target changes targeting performance with a mouse. Mirroring results for a real-world reach-to-grasp task [8], subtask one of the high-precision task (dock) had a longer movement time, longer deceleration phase, and lower velocity just prior to click, though all tasks had the same initial aiming movement. Conversely, subtask one of the lower-precision tasks (target, dual) had shorter movement times, shorter deceleration phases, and higher click velocities.

These results show that the changes in movement time can be attributed to the differences in the secondary feedback-correction phase, and not the initial ballistic phase of aiming. Mirroring [8], our results can be explained by the precision requirements; as precision of the objective increases, so does MT– the deceleration phase is lengthened and the velocity profile shape is changed through a longer proportion of movement in deceleration. We speculate that the motor planning and control for the second subtask is encapsulated within the second phase of the first subtask.

Our flick task was intended to mirror the low-precision 'throw' task in [8]; however, participants' comments made it clear that our implementation of flick required precision. We used velocity of the cursor just prior to release to give velocity to the target and did not incorporate momentum of the cursor just after release of the mouse. Users found this task to require more precision than the two targeting tasks, and our results show no differences in any of the measures between flick and dock. Future work will study alternative low-precision tasks and implementations of flick.

Relative Impact of ID and Task

Movement time is primarily determined by index of difficulty, as shown in Equation 2. The variance in MT due directly to manipulations in ID is high; η^2 for the effect of ID on MT was .94. Although the variance in MT due to task was smaller (η^2=.28), task produced significant differences. The intended use of an object has impact on the initial aiming movement to that object, although movement time will still be determined primarily by ID. Our interaction effect of ID and task on MT showed that for the two easiest targets (smallest IDs), there were no MT differences for the two low-precision tasks (target and dual target). Thus the easiest aiming movement, as defined by the combination of task and ID, did not show MT differences.

Implications for HCI

Most research in HCI that models aiming is conducted with highly-controlled tasks in an laboratory setting. Our results show that users' intended use of an object will impact the movement time and motion kinematics of the initial aiming movement to acquire the target. Researchers in HCI should acknowledge the effect of intended use on movement time and motion kinematics and be aware of how their choice of task (high or low precision) will affect their results.

Our results have particular importance for endpoint prediction. There is a recognized need for endpoint prediction to realize targeting assistance techniques that have been developed in the laboratory [4]; however, prediction techniques using motion kinematics will lose accuracy because of the variability in motion kinematics depending on intended use. Smart techniques that consider common uses of different widgets may improve accuracy.

Finally, there has been little effort to study Fitts's law in real computer use due to difficulties in data gathering and processing. For example, choosing tighter constraints on classifying targeting motions will invariably improve the model's performance. In lab studies, researchers control the task; thus, intended use has little impact on the performance of the model. To model aiming movements in real computer use, the intended or actual use of an acquired target will need to be noted and accounted for in the modeling process.

CONCLUSIONS

This research presents the first evidence that the intended use of a target affects its acquisition in terms of movement time and motion kinematics for computer aiming tasks. Our results are important for researchers who model aiming on a computer, and have particular impact for research that uses kinematics, (e.g., endpoint prediction), or that attempts to model aiming in real-world computer use.

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