Analyzing Intended Use Effects in Target Acquisition

Jaime Ruiz
Department of Computer Science
Colorado State University
Fort Collins, Colorado 80523
jgruiz@cs.colostate.edu

Edward Lank
Cheriton School of Computer Science
University of Waterloo
Waterloo, Canada N2L 3G1
lank@cs.uwaterloo.ca

ABSTRACT

Recent work by Mandryk and Lough demonstrated that the movement time of Fitts-style pointing tasks varies based on intended use of a target, suggesting major implications for HCI research that models pointing using Fitts' Law. We replicate the study of Mandryk and Lough to determine exactly how and why observed movement times vary. We demonstrate that any variation in movement time is the result of differences in additive factors (a in Fitts' equation) and can be attributed to changes in the time a user spends over their primary target.

Categories and Subject Descriptors

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

General Terms

Human Factors

Keywords

Pointing, Fitts' Law, motion kinematics, intention

1. INTRODUCTION

Most human-computer interaction researchers who study Fitts' Law use discrete pointing tasks as the basis for their experiments (e.g. [1,2,3,12,13,22,24,26]). In a discrete pointing task experiment, the participant performing the experiment moves from an initial position to a target and, once on the target, clicks the mouse to signify the end of the task. However, in real-world interfaces, objects acquired by users can be manipulated in various ways. Targets can be clicked, they can be acquired and moved, or they can be the first in a sequence of repeated clicking and moving tasks. These differing possible target manipulations have been called the *intended use* of the target [14].

In physical pointing and grasping, the intended use of a physical object has an effect on the spatio-temporal characteristics of movement, i.e. the position, speed, and acceleration with respect to time [11,15,18]. Collectively, we call these spatio-temporal characteristics of movement the *kinematics* of movement or *kinematic profiles* of movement.

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Recently, Mandryk and Lough [14] demonstrated that the movement time of Fitts-style pointing tasks varies based on intended use of the target. They examined four common intended uses of on-screen objects. These were: single targeting, where the user presses and releases the mouse button over a target; dual targeting, where the user first clicks on one target and then moves to and clicks on a second target; flicking, where the user presses the mouse button down on a target and quickly and imprecisely directs the target to another position on the screen; and docking, where the user presses the mouse button down on a target and carefully repositions it within a tightly constrained region on the display.

Mandryk and Lough analyzed the initial targeting task, i.e. the task of moving from a start position to the target location before performing the intended use task. We call this first target the user's *primary target*. The researchers demonstrated that the movement time of Fitts-style pointing tasks varies based on intended use of the primary target; i.e. that the time taken to press the mouse button over the primary target varies depending on the subsequent task to be performed and that these changes mainly occur shortly before clicking the target (i.e., during the corrective phase of motion).

Temporal variations in on-screen targeting are of concern to Human-Computer Interaction (HCI) researchers, as we model pointing using Fitts' Law [12]. The goal of this paper is to determine exactly how and why observed movement times vary. More specifically, we wish to ensure the ecological validity of Fitts' Law studies in HCI in light of temporal variations resulting from intended use.

In this paper, we demonstrate that variations in time due to intended use are a result of changes in the start-stop time of the device (the constant a in Fitts' Law) [6]. Further, we show that the time spent acquiring a target is statistically indistinguishable across tasks, and that the only statistically significant variation in time is the time a user spends over their primary target with their mouse near motionless before beginning their secondary task. We discuss the implications of this observation for modeling real-world interaction tasks.

The rest of this paper is organized as follows. We first highlight relevant related work. Next, we describe our experiment replicating the intended use study of Mandryk and Lough. We present results of our intended use study, first examining motion profiles and then analyzing the specific nature of the differences in movement profiles. Finally, we discuss the implications of both our results and Mandryk and Lough.

2. RELATED WORK

2.1 Fitts' Law in Human-Computer Interaction Research

Woodworth [25] is credited as the first researcher to observe the speed-accuracy tradeoff of goal-directed movement (i.e. targeting). He hypothesized that goal directed motion is made up of two components; an *initial adjustment phase* (often referred to as the ballistic phase or the initial impulse) and the *current control phase*. The initial adjustment phase of the movement is relatively rapid and serves to bring the limb into the vicinity of the target. In the current control phase of the movement, the participant adjusts the movement in order to hit or come close to the target. Virtually all contemporary models of motor control and learning have been grounded in Woodworth's two-component model of goal-directed movement [5].

Fitts' Law [6,12] is the quantification of the speed accuracy tradeoff first observed by Woodworth. It that relates movement time, *MT*, to target size and distance through a logarithmic term known as the *Index of Difficulty* (ID). In HCI research, MacKenzie [6,12] presented a variant of the original Fitts' Law equation (the Shannon Formulation) and showed that this variant most accurately reflects experimental data for mouse-based pointing tasks, i.e. that:

$$ID = log_2\left(\frac{A}{W} + 1\right) \quad (1)$$

$$MT = a + bID \quad (2)$$

In Equation 1, A represents the distance to the target, and W represents the size of the target. In Equation 2, a and b are empirically defined constants. The reciprocal of b, $\frac{1}{b}$, is known as the *Index of Performance* (IP) [12]. The IP, and therefore the slope of the MT plot, can be affected by various factors such as the direction of movement and the specific input device used for the targeting task [12]. Finally, the constant a, the y-intercept, is what MacKenzie [6] calls *additive factors* in pointing tasks, i.e.:

> "*Target acquisition tasks on computers are particularly sensitive to additive factors. The select operation, which typically follows pointing, may entail a button push, the application of pressure, dwell time, and so on. These responses should have an additive effect, contributing to the intercept of the regression line but not the slope.*" [12 pg. 98]

To fully analyze the behavior of computer users during pointing movement, a kinematic model of movement is valuable, as it models instantaneous characteristics of movement, rather than simply overall movement characteristics (such as time). Several researchers have proposed models of the kinematics of the pointing motion described Fitts' Law (see [5,19] for a review). The current commonly accepted model in HCI literature [9,14,22] is Meyer et al.'s stochastic optimized submovement model. The model states that targeting begins with a ballistic movement towards the target. If the movement lands within the target, the task is complete. However, if the movement lands outside of the target, another corrective movement is needed, which, again, can land inside or outside of the target. The subject's task is to reach the target as quickly as possible. To reach the target as quickly as possible, the subject should make a very rapid initial movement, but this would result in greater imprecision. Alternatively, the subject could be slow and precise in their initial movement to increase the likelihood or hitting the target. However, this would result in very long initial movement times. Goal directed movement is a stochastic optimization problem, where the increased error rate of higher motion amplitudes (with higher probability of secondary impulse) trades off against the shorter time to traverse the distance to the final target due to faster speed. According to Meyer et al. [17], Fitts' law represents such an optimal balance.

Several researchers have examined the kinematics of goal directed motion and the influence various factors have on the kinematic profile of motion. MacKenzie et al. examined the effects distance and width have on the peak velocity reached during the ballistic phase of motion and the time spent decelerating (current control phase) in 3D pointing [11]. The researchers found that for targets with similar IDs, the percentage of time spent before and after peak velocity was affected by target size, whereas the magnitude of ballistic movement (the peak speed) was determined by movement amplitude. Follow up work by Walker et al. [23] observed similar changes in the kinematic profiles but attributed the increase of time spent during the deceleration phase primarily to an increased time spent in the verification phase of movement (i.e., the time spent after movement before clicking the target). More recently, Lank et al. [9] used the *Minimum Jerk Law* to model the initial ballistic submovement of pointing tasks. They show that this model of initial ballistic movement can be used to infer the endpoint of a goal-directed movement in a user interface.

2.2 Kinematics of Physical Pointing and Grasping

Marteniuk et al. [15] investigated the effects of motion constraints on movement time and the kinematic profile of motion when pointing (i.e. touching) and grasping physical objects. They observed faster movement times for pointing. The observed differences were a result of both longer acceleration and longer deceleration phases during grasping movement. The researchers also found that the mean speed before making contact with the target was significantly higher when pointing than when grasping. Finally, Marteniuk et al. found that the perceived affordances of the target had an effect on the kinematic profile of movement. When asking subjects to grasp a tennis ball or light bulb, Marteniuk et al. observed that movement times and the deceleration phase were significantly longer for the light bulb versus the tennis ball.

Intention has also been shown to have a significant effect on motion kinematics and observed time. Marteniuk et al. [15] showed that movement times and motion profiles differed depending on if an object was to be thrown or carefully placed after grasping. Follow up work by Rossenbaum and his colleagues also supported and extended these findings, showing that the perceptions of affordances and the intended use of an object both significantly affect grasping movement [18].

2.3 Effects of Intended Use in User Interfaces

Recently, Mandryk and Lough [14] extended the work of Marteniuk et al. to 2D pointing in user interfaces. Mandryk and Lough looked specifically at the effect intended use (e.g., single target, dual target, flick and dock tasks) has on movement times to the primary target of a goal directed movement. In their experimental design, they measure movement time from the moment a user clicks within a start location until the moment when a user clicks the mouse button over the primary target, i.e. the target of their first targeting movement. Once the user has depressed the mouse button over the primary target, they then perform one of the three secondary tasks.

Mandryk and Lough make several observations. First, they show that for their experimental configuration, flick and dock take significantly longer than single target and dual target. They do, however, note that their flick task may have been more difficult than they anticipated it should be, based upon comments from their participants [10 pg. 1652]. As a result, flick data in their research may not be reliable. Second, Mandryk and Lough divide motion toward the target into two phases. The first phase, the *acceleration phase*, occurs from the time a user clicks within the start location until peak speed. The second phase, the *deceleration phase*, occurs from peak speed until the moment a user depresses the mouse button within the primary target, before beginning the secondary task. They show that the deceleration phase of movement is shorter for both single target and dual target than for the docking task. They also show that peak velocity is statistically faster for flick than for single target or dual target.

Mandryk and Lough note that one significant implication of their work is that there appears to be a difference in the acceleration phase of movement (i.e. peak speed is higher for the flick task) and the deceleration phase of movement (i.e. in fraction of time spent after peak speed) depending on intended use of the primary target. The implication that they draw from these observations is that the differences in motion may affect interaction techniques that depend on an analysis of kinematics (e.g. endpoint prediction [9]).

2.4 Open Questions

In their work on expanding targets, McGuffin and Balakrishnan [16] note that many pointing facilitation techniques are ineffective in situations where targets are densely packed on the display. Examples of these dense arrangements include ribbons, toolbars, or menus. Furthermore, in application programs, the program content (a character, a cell, a pixel) may also constitute legitimate targets, meaning that pointing facilitation may frequently encounter situations where the display is tiled with potential targets for pointing tasks. McGuffin and Balakrishnan state that for any pointing facilitation technique to be effective in these configurations, some reliable mechanism for predicting endpoint is essential. As a result, they argue that endpoint prediction is an important task in practical pointing facilitation. In their paper, Mandryk and Lough note the potential effects of intended use on the kinematics of movement. Therefore, one question we wish to address is whether or not pointing facilitation techniques that use the kinematics of movement [3,9] are affected by kinematic variations resulting from intended use.

Furthermore, while differences may exist in time, Mandryk and Lough provide little data on how (or even whether) Fitts' Law models movement time for variations in intended use. Assuming that the linear relationship between movement time and ID is preserved for different intended uses, whether we observe changes in *ID*, *IP*, or *a* in the Fitts' Law equation (Equation 2) is an open question.

Finally, the deceleration phase of movement encompasses all user action from peak speed until they depress the mouse over the target. Mandryk and Lough state that changes can be observed during the sub-movement phase of motion, but provide little guidance on where, during deceleration, the changes in movement time occur. Is the entire deceleration curve affected? Or does the user simply spend a bit more time hovering over the target after movement stops before pressing the mouse button to begin his or her secondary task?

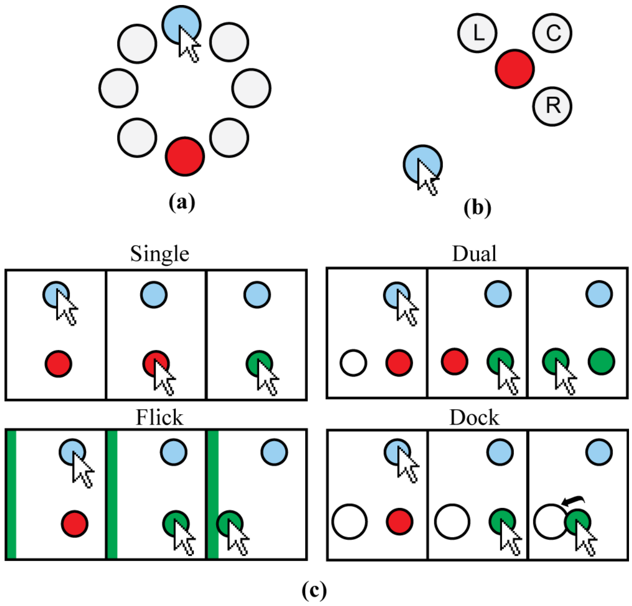

Figure 1: (a) The standard ISO 9421-9 targeting task. (b) Our modified task and the possible secondary target locations. (c) Task conditions for the study. Frame 1 – Start location; Frame 2 – the primary task; Frame 3 – the sub-task to be performed.

As a result of these open questions, we now present a replication study that analyzes the kinematic and temporal characteristics of the intended uses originally analyzed by Mandryk and Lough.

3. METHOD

3.1 Apparatus

The experiment was conducted on a generic desktop computer (Core 2 Duo, 3.0GHz) with a 17-inch 1280x1024 LCD display (mimicking Mandryk and Lough) running custom software written in C#. Input was collected using a Microsoft Sidewinder X3 mouse with cursor acceleration set to the Windows operating system default level.

3.2 Tasks

The task conditions were the same as described by Mandryk and Lough and required participants to perform an initial aiming movement (primary task) in addition to a secondary subtask. Our primary task differs from Mandryk and Lough in that we opted for a modified version of the ISO 9421-9 [8] targeting task (shown in Figure 1(a)) to vary the direction of movement. Eight circular targets were arranged in a circle with a radius of *D*. Our ISO 9421-9 targets differ from the standard ISO setup in that we only displayed the starting target (represented by the color blue) and the final target (represented in red). After completing the full task (primary and secondary), the task would continue with the previous primary target becoming the new start target. This sequence would continue until all eight targets were traversed (resulting in 9-targeting tasks per arrangement).

At the onset of the trial, the primary task target was colored gray. The task began when the participant moved the cursor into the blue colored starting area and hovered for approximately one second. At that time, a red target would appear on the display. As in previous Fitts' tasks, participants were required to move the cursor the red target as quickly and accurately as possible. By requiring the user to hover over the start target, our task prevents the user from performing moving off the start target before the primary target is displayed (referred to as *start errors* in Mandryk and Lough [14]).

The secondary tasks were replicated from Mandryk and Lough and included:

- *Single Targeting Task:* For the targeting task condition participants were not required to perform a secondary task. Therefore, only the primary task was performed. This task condition replicates the task normally performed in Fitts-style studies.
- *Dual Targeting Task*: In the dual targeting task, the user is presented with two targets, the primary target and the secondary target. Once the user completes the primary task by clicking on the primary target, the secondary target turns red. The user is then required to click on the secondary target.
- *Flick Task:* For the flick task, the participant is presented with the primary target and a 35-pixel green border on an edge of the screen. The participant was told to move the primary target (primary task) and flick the target in the direction of the green-border. Mandryk and Lough created the flick task to echo the throwing task of Marteniuk et al. [15].
- *Docking Task:* In the docking task the user is presented with the primary target and a docking region, represented by a white disk 20 pixels larger than the primary target. The participant was required to move to the primary target and drag the target into the docking region. Mandryk and Lough created the docking task to echo the fitting task of Marteniuk et al. [15]

Location of secondary targets was randomized to one of three locations (collinear, left, or right) in relation to the direction of motion as shown in Figure 1(b).

3.3 Design and Procedure

The studies consisted of a 4 (task) by 3 (target width) by 3 (target distance) within-subjects design with repeated measures. For the primary task, target widths (W) of 30, 60, and 120 pixels were each shown at a distance (D) of 150, 300 and 600 pixels. The resulting D/W combinations provided *Indices of Difficulty* (ID) between 1.17 and 4.39, echoing Mandryk and Lough's IDs.

The study consisted of six blocks, two blocks for each task condition. The first block was a training block and was omitted during our analysis. Within each block, participants were presented each D/W combination in random order resulting in 81 trials per task condition (324 trials per participant). Ordering of the task condition was counter-balanced using a 4x4 Latin Square.

3.4 Dependent Measures

As in Mandryk and Lough, all dependent measures focused on the initial task of acquiring the primary target and were calculated using the logs generated from our custom software. For each trial, we interpolated movement to create time-equidistant points along the gesture. Using the equidistant points we calculated speed and position at each point. Speed was smoothed using an interpolating degree 2 polynomial as described by Lank et al. [9]. This degree 2 polynomial naturally smooths the curve without the dampening effects on peak speed that occur when using a sliding window.

For consistency, our dependent measures were the same as Mandryk and Lough and included:

- *Movement time (MT):* Movement time is defined by the temporal interval between the first detected mouse movement and the mouse down event on the primary target.
- *Overshooting errors:* Overshooting errors, referred to by Mandryk and Lough as exit errors, are errors in which the participant exited and re-entered the primary target prior to mouse-down.
- *Peak speed (S_{max})*: Peak speed is simply the maximum speed reached during the primary task.
- *Time to peak speed (tS_{max})* and *Percent after peak speed ($\%afterS_{max}$)*: Time to peak speed is the temporal measure taken to reach peak speed and represents the acceleration phase of the motion. Percent after peak speed is the amount of time that occurs after peak speed is reached as a percentage of total movement time and represents the deceleration phase of the motion.
- *Click speed*: Click speed is defined as the mean speed over the 33ms prior to selecting the primary target.

3.5 Participants

We recruited 52 participants (22 female) from two North American universities to participate in the study. Participants were aged between 18-35 ($\mu=23.5$, $\sigma=5.0$) and all were right-handed mouse users. Participants were compensated $10 for participating. The study took approximately 60 minutes.

4. RESULTS

Of the 16,848 tasks recorded, 1.9% resulted in the user not correctly hitting the primary target and were removed from analysis. There was no statistical difference in error rate between task conditions.

4.1 Comparison to Mandryk and Lough

In this section, we briefly outline the similarities and differences between our results and those presented by Mandryk and Lough. In the next section, we provider a more detailed analysis of kinematic profiles to diagnose exactly why the observed differences occur.

We conducted a repeated measures RM-MANOVA on MT, overshot errors, S_{max}, tS_{max}, $\%afterS_{max}$, and click speed with ID and task condition (i.e. intended use) as factors. Similar to Mandryk and Lough, when the sphericity assumption was violated degrees of freedom were adjusted using the Huynh-Feldt method. Post-hoc analysis was performed for dependent measures using Bonferroni correction.

4.1.1 *Effects of ID*

Similar to Mandryk and Lough, we observe significant effects of ID on all measures ($p < .001$ in all cases, $.48 \leq \eta^2 \geq .81$). Bonferroni corrected pairwise comparisons show:

1. Significant differences exist for MT and peak speed for all IDs ($p < .001$). As expected, as the index of difficulty increased so did participants' MT and peak speed.

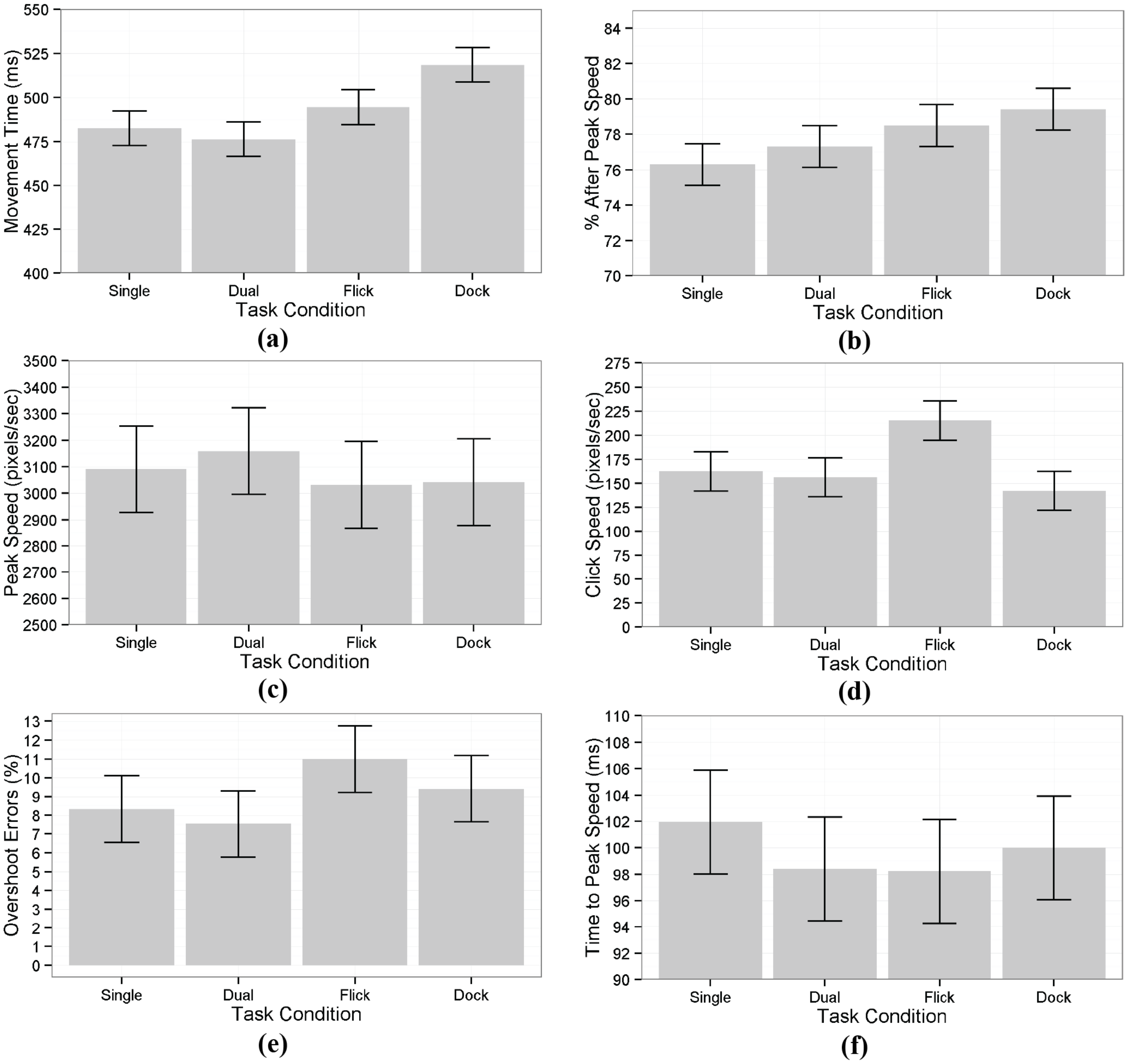

Figure 2: Dependent measures by task condition (error bars 95% CI). (a) Movement time. (b) Percent of gesture after peak speed. (c) Peak Speed. (d) Click speed. (e) Percent of overshoot errors. (f) Time to peak speed.

2. For time to peak speed (tS_{max}), significant differences exist between all IDs (*p < .001*) except for the middle two IDs (2.58 and 3.46). Results show that as ID increases so does the time to peak speed.
3. Percent after peak speed shows a significant difference between all IDs (*p < .001*), demonstrating that the deceleration phase of the movement increases as the index of difficulty increases.
4. Analysis of click velocity shows it decreases as ID increases (*p < .05* in all cases), with the exception of the two highest IDs, which were found to not to be significant (*p > .61*).
5. Significantly fewer overshot errors occurred for the two lowest IDs (1.17 and 1.81) than the higher IDs (*p < .001* in all cases).

There were no significant ID*task condition interaction.

4.1.2 *Effects of Task Condition*

Means and 95% confidence intervals for our dependent measures by task condition are shown in Figure 2.

Movement Time and Exit Errors

Similar to Mandryk and Lough, analysis of variance shows a significant effect of task condition on movement time ($F_{2.5,127}=16.03$, $p < .001$, $\eta^2=.05$). Pairwise comparisons show only the dock task to be significantly different than other task conditions ($p < .01$). Unlike Mandryk and Lough, who found significant differences between flick and the single and dual target conditions, we only observed flick to be significantly slower than the dual target condition ($p < .05$).

In contrast to Mandryk and Lough, we observed a significant effect of task condition on overshooting errors ($F_{3,153}=6.5$,

$p<.001$, $\eta^2=.02$). Post hoc analysis shows the flick task to have significantly higher occurrence of overshooting errors than the single and dual target conditions ($p < .05$ in both cases).

Velocity-based Measures

Similar to Mandryk and Lough, analysis of variance shows a significant effect of task condition on fraction of time after peak speed, %afterS$_{max}$ ($F_{3,153}=90.59$, $p < .001$, $\eta^2=.04$). Post-hoc analysis using Bonforroni correction shows %afterS$_{max}$ to be significantly higher for the dock task condition compared to the single and dual targeting task ($p < .001$ in both cases). We also observed a higher %afterS$_{max}$ for the flick condition compared to the single target conidtion; an observation not seen by Mandryk and Lough.

Contradictory to Mandryk and Lough, we see no significant effect of task condition on peak speed ($p > .07$). Mandryk and Lough found that flick had significantly higher peak speed than other task conditions. Qualitatively, we note that, in our experiments, the flick task condition actually had the lowest peak speed.

Similar to Mandryk and Lough, we see a significant effect of task condition on click speed ($F_{3,153}=22.7$, $p < .001$,$\eta^2=.07$). However, Mandryk and Lough found that click speed for flick and dock to be slower than for single target and dual target. In contrast, we found click speed for flick to be significantly *faster* than for all other conditions ($p < .001$ for all conditions). No other significant differences were found.

Lastly, as with Mandryk and Lough, no significant effect of task condition was observed on time to peak speed.

4.1.3 *Synthesis with Mandryk and Lough*

In general, our results support the observations of Mandryk and Lough that intended use has an effect on movement time. Specifically, if the secondary task is to dock the primary target, i.e. to drag the primary target to a restricted screen location, then movement time increases. We also see that the increase in time is observed specifically in the deceleration phase of movement, i.e. the phase of movement after peak speed until the user clicks on the primary target. The one minor point of contrast is in our data for the flick task. However, Mandryk and Lough have acknowledged that their flick task was poorly designed and may be hard to replicate [14]. In the end, the flick task is immaterial: Their primary result, that intended use affects movement time, is supported by our results for dock.

Mandryk and Lough's primary concern with disparities in movement time based on intended use is that the effect may represent a significant alteration of the kinematic profile. The two potential areas of concern are the possible changes in kinematics of the dock task based on the increased time taken during the deceleration phase, and the observed higher click speed of the Flick task.

4.2 Kinematic and Temporal Analysis Based Upon Intended Use

It is important to note that many aspects of user movement may affect movement time and time spent during the deceleration phase of movement. Beyond variations in the kinematics of deceleration, variations may exist in the effective target width, and variations may exist in the amount of time a user spends over a target before pressing the mouse button, either at the beginning or the end of a pointing movement. The first question we must answer is where, exactly, during deceleration do variations in the kinematics of movement occur.

To answer this question, we first examined the average normalized speed versus distance profiles of end-user motion for each of the task conditions. When we examine these normalized profiles, shown in Figure 3, we see that all deviations in profiles are concentrated near the end of movement.

Next, to ensure that subtle variations in movement did not affect kinematic endpoint prediction, we applied the kinematic endpoint prediction technique as described in [9,21] to each trial collected during our study. Using 90% of gesture motion, we calculated the frequency with which the technique correctly identified the participant's intended target. Repeated measures ANOVA on prediction accuracy (i.e. the frequency of identifying the correct target) with task condition and ID as factors showed no significant effect for task. Therefore, we conclude that intended use does not affect the accuracy of Lank et al.'s kinematic endpoint prediction technique.

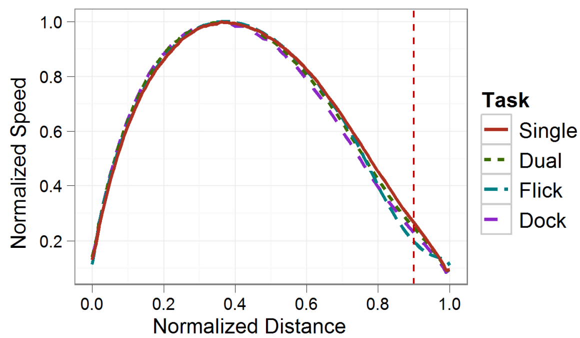

Figure 3: Normalized kinematic profiles by task condition.

Because of the similarities in the normalized and averaged kinematic profiles of each task and the lack of effect on kinematic endpoint prediction, we became interested in exactly why the discrepancies in movement time between dock and the other intended use tasks were observed.

Given that Fitts' Law has become one of the most robust and highly adopted models of human movement [5], changes in MT based on intended use must either have an effect on *a*, *b*, and/or ID. We plotted MT versus ID for each task condition, as shown in Figure 4, to determine how the intended use of a target affects Fitts' Law. As expected, we observe a high correlation ($R^2 \geq .99$) between MT and ID as described by Fitts' Law for all task. Therefore, Fitts' Law applies to each of the targeting tasks, regardless of intended use. Furthermore, the high correlation allows us to conclude that differences in MT between the dock task and other task conditions are not affecting the logarithmic expression of ID. As a result, unlike in finger touch targeting [4], ID does not need to be modified to account for intended use.

Next, we considered a possible change in the slope (*b*) of the MT versus ID graph, i.e. a change in the Index of Performance of the targeting task. Our graph clearly shows the consistently higher MT of the dock task. However, the slope of dock's MT vs. ID line is virtually identical to the slopes of the other lines. There is no significant difference between the average slopes of the various lines (p > .10).

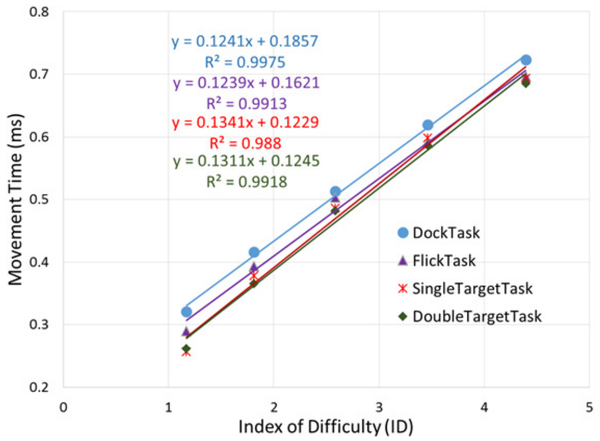

Figure 4: Movement time by ID for each task condition.

Finally, we examined changes in the intercept (a) that represents additive factors unrelated to ID and IP. Figure 4 clearly shows differences between the intercept of the dock task and other tasks, suggesting a higher additive effect for the dock task. The additive effects should primarily occur at the end of motion, a result of observed differences in %afterS_{max}. To analyze differences in %afterS_{max} more thoroughly, we define MT as a combination of the time to move from the initial location to the primary target (T_{move}), followed by the time a participant hovers over the final target (T_{hover}), i.e.:

$$MT = T_{move} + T_{hover} \quad (3)$$

We would expect to see changes in T_{hover} and not T_{move} if the change in MT can solely be based on additive factors. Thus, we calculated T_{move} and T_{hover} for each trial, where T_{hover} was defined as the time spent within a 5-pixel radius of the final click location[1]. The resulting means by tasks are shown in Figure 5.

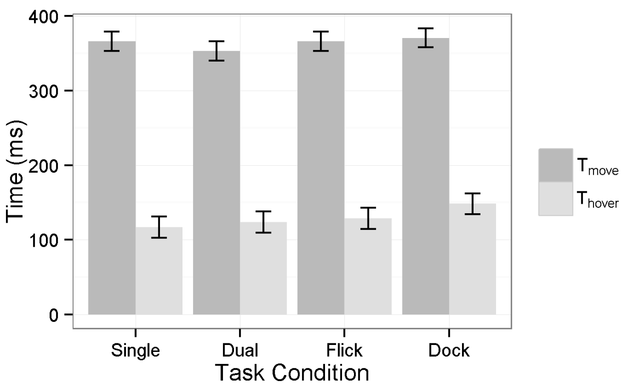

Figure 5: Means for T_{move} and T_{hover}.

We performed a RM-ANOVA on T_{move}, and T_{hover} with ID and task condition as factors. As expected, we found that ID has a significant effect on MT, T_{move}, ($F_{2.6,99.45}$)$=135.3$, $p < .001$, $\eta^2=.99$) and T_{hover} ($F_{2.6,99.45}$)$=459.9$, $p < .001$, $\eta^2=.42$).

[1] We also examined calculating T_{hover} as the time spent within the primary target were the current speed was 5% of the movements peak speed. We opted to use the 5-pixel radius because we observed identical results and we considered the 5-pixel radius measure to be a more conservative measure of dwell time.

However, we are interested on effects of *task condition*, i.e. of intended use, on T_{move} and T_{hover}. We observed a significant effect of task condition on T_{hover} ($F_{3,153}$=12.5, $p < .001$, $\eta^2=.05$) ***but not on*** T_{move} ($p > .10$). Post-hoc analysis using Bonferroni correction shows the dock task condition to have significantly longer hover times than all other tasks ($p < .01$ in all conditions).

Our data supports the hypothesis that the increase in MT observed is a result of an increase in the additive factors, i.e., hover time over the primary target after motion stops. As well, if timing is examined in detail, our observations support the premise that the increase in hover time over the primary target entirely accounts for the observed increase in movement time from an initial position to that primary target. In Figure 3, differences in T_{hover} are equivalent to differences in the y-intercept in the equations in Figure 2.

In summary, given that the time to move to the target (T_{move}) is statistically the same across all task conditions and no observed differences exist in the time required to reach peak velocity from the initial position, we can conclude that any difference in the %afterS_{max} measure and in MT is the result of statistically significant variations in time spent hovering over the primary target after acquiring the target.

5. DISCUSSION

The observation of Mandryk and Lough that intended use affects movement time is both accurate and significant to modeling movement time with Fitts' Law. HCI researchers have long used Fitts-style pointing task and Fitts' Law with the rationale that it will generalize to real-world situations. However, in real-world situations users manipulate targets after acquiring them, and our results demonstrate that the intended use of a target results in changes in hover time over the target. Therefore, to maintain external validity between real-world tasks, we may wish to consider redefining the termination of a task (acquiring a target). Instead of using the mouse down event, we should consider using the point in time where the cursor is over the target and speed approaches 0. By defining the task in such a way, we eliminate additional additive factors from the user hovering.

Another significant implication of these observations involves the mental processes that underlie compound tasks that involve targeting an on-screen object and then acting on that object. Our results suggest that it is possible that participants may view the mouse-down action over the target as the beginning of the drag task for our dock condition, as opposed to the end of the primary targeting task. In participants' mental model of target acquisition, it seems possible that positioning the cursor over the target, rather than clicking on the target, may signify completion of the targeting task. Other user interface tasks may also involve subtle aspects of serialization that must be teased out to bound real-world pointing tasks [7,10,20].

Furthermore, the validation of Mandryk and Lough's results for the dock task speaks to the relative cognitive cost of planning a dock versus flick, single or dual target task. In psychology research, the temporal cost of initiating an action is frequently used as a proxy of the relative cognitive cost of planning that action, i.e. if it takes longer to initiate a task, then the planning of the task must demand more cognitive load [20]. Mandryk and Lough's observation of the increase in time before beginning the dock task is an indication of the relative increase in cognitive load caused by docking versus the other tasks evaluated.

Beyond the specific cognitive costs of docking versus flicking or targeting, understanding the relative cognitive costs of a broad set of user interface tasks can inform the design of interfaces by encouraging designers of these interfaces to opt for less cognitively demanding interface tasks. Accurately assessing the relative planning time of different tasks can be difficult, simply because it is difficult to accurately measure the onset of the planning action. The tight control of a Fitts' Law study, coupled with the performance of a secondary task, is a good mechanism for teasing out the specific increase in cost placed on the user in planning different interface tasks. In other words, exploring user interface tasks as a combination of pointing and performing the task allows us to accurately identify the changes in planning time because of the accuracy of Fitts' Law in modeling pointing time. Any variations in the mouse-down action must arise from planning costs associated with the secondary task.

6. CONCLUSION

In this paper, we extended the work of Mandryk and Lough and showed that any observed variation in movement profiles and movement time caused by intended use occur in the last 90% of motion and are accounted for by changes in the time a user spends dwelling over their primary target.

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