Pointing on a Computer Display

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ABSTRACT
Pointing movements with the hand were used to control directly a cursor to point to targets on a graphical display with different gain settings. A detailed analysis of both the cursor and hand movements showed how features of the movements scale over a wide range of distances and target widths. Cursor movements showed gain effects, while hand movements were relatively unaffected by gain. The results suggest that considering the behaviour of the hand, rather than the cursor, will lead to more effective modelling of human performance with certain types of pointing devices.

KEYWORDS: Human performance modelling, input devices, Fitts' law, pointing.

INTRODUCTION
Pointing movements are elemental in many forms of human-computer interaction with 2D and 3D graphical displays. Here we attempt to make a connection between research on human perceptual-motor processes in dealing with the physical world, and more abstract interactions with pointing devices. Fitts' law is widely used to describe speed-accuracy tradeoffs in both contexts [2]: movement time (MT) = a + b ID, where ID is log(2A/W). A is the distance to be covered and W the width of a target. Numerous studies in the HCI literature have analyzed the behaviour of a cursor, and report widely varying measures (values of a and b) for similar processes [2].

Human pointing movements can be analyzed in terms of two phases: an initial planned impulse to a peak velocity, and a further deceleration to the target under current control [5]. The timing and magnitude of the first velocity peak may be a function of the distance to be covered [3]. Others [1] have shown that for equal ID, the shape of the velocity profile of the movement is asymmetrical, more time being spent in deceleration as target width decreases. For a pointing device using various gain settings, there are two distances to consider: distance of the hand movement, and distance of the cursor movement on the display. There are also and two widths: visual size on the display, and width as an accuracy constraint for hand movement.

This study uses the finger of the hand as an input device, making pointing movements, as studied by human movement researchers, to control directly a cursor on a display. By varying the gain we address the question of whether distance and width in display space or hand space better describe the systematic effects on movement kinematics discussed above.

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METHOD
Subjects
Six right-handed university students who had some experience with pointing devices were paid to participate in the study.

Equipment
An OPTOTRAK system (Northern Digital, Waterloo) was used to sample (60 Hz) and record in three dimensions the position of infrared markers placed on the subjects' index finger. Position data were projected in real time on a reference frame in the plane of the table top, and used to control the position and orientation of a cursor (red arrow, 3 by 1 cm) on an SGI Indigo graphics display. Targets were represented on the screen as white circles on a black background.

Procedure
The subject placed the right hand on a table to the right of the display, index finger extended. With the cursor positioned on a start mark, a target was presented on the display, and the right index finger was used to point as quickly as possible to a spot on the table top so as to position the tip of the red arrow anywhere inside the displayed target.

Three blocks of trials were performed with a different gain setting (1, 2, and 4) for each block. A practice session before each block allowed the subject's performance to stabilize before performing trials. Five different target widths (3 to 48 mm) and distances (19 to 300 mm) were used in combination. The order of presentation of gain was counterbalanced, while width and distance combinations were randomized to appear 12 times in each block of trials.

RESULTS
Data for cursor and index finger position were processed to yield tangential velocity profiles for each trial. Four kinematic features were were analyzed as dependent measures. Using a subset of width and distance combinations within blocks, gain (3) by distance (3) by width (3) analyses were performed separately for both display space and hand space using ANOVA with repeated measures. Significant effects are outlined below for:

movement time (MT), peak velocity (pv) along the path of the movement, time to peak velocity (tpv), and per cent time after the first deceleration peak (ptapd). All results in tables 1 and 2 are significant to $p < .001$, with the exception of those marked with a * ($p < .05$).

Table 1. Display Space Analysis of Kinematic Measures

	Gain			Distance (mm)			Width (mm)		
	1	2	4	75	150	300	12	24	48
MT (ms)	858	791	760*	651	786	973	884	800	726
pv (mm/s)	501	568	645	338	515	861	561	566	588
tpv (ms)	265	230	185	179	272	279			
ptapd	60	64	71				68	66	61

Table 2. Hand Space Analysis of Kinematic Measures

	Gain			Distance (mm)			Width (mm)		
	1	2	4	19	38	75	3	6	12
MT (ms)				599	723	866	811	732	645
pv (mm/s)	187	179	161*	120	156	251	173	174	179
tpv (ms)				154	179	230			
ptapd							68	66	62

Movement Time (MT)

In both analyses, MT increased with larger distances and smaller targets, as predicted by Fitts' law. Viewed from display space, movement time decreased considerably with increasing gain. No gain effect was evident in hand space.

Multiple regression on the combined data provided a mediocre fit to Fitts' model. In this case,

$$MT(ms) = 352 + 118\ ID,$$

with a multiple R squared of .75. A better fit was provided by Welford's model [4] which separates the distance-covering and visual control mechanisms:

$$MT = a \log A - b \log W + c.$$

In this case,

$$MT(ms) = 153 \log A - 83 \log W + 129$$

with a multiple R squared of .97.

Peak Velocity and Time to Peak Velocity

In display space and hand space, peak velocity increased markedly with increasing distance, with small effects for target width and gain. In display space, there was a large decrease in time to peak velocity with higher gains. Both analyses showed a clearly separable effect of distance in the timing of peak velocity, independent of target width.

Per Cent Time After Peak Deceleration

Both analyses showed a separable effect of width on the proportion of time spent in deceleration to the target, independent of distance. In display space, there was a large effect of gain, with higher gains increasing the proportion of time in deceleration.

DISCUSSION

As in other studies [4] involving large variations in distance, target width has less effect than distance on movement time, even though Fitts' model holds for small subsets of the data. One interpretation is that in HCI, hand and display space are not superimposed, requiring a cognitive strategy to use vision to control the endpoint rather than a more direct visuomotor mechanism, reducing the sensitivity of the channel for visual control. Viewed from display space, gain affects the scale of hand movements, and thus alters movement times for equal IDs. The timing of peak velocity of the hand is a good predictor of its final position independent of gain, whereas the overall shape of the velocity profile is affected by the width in hand space, regardless of gain.

Overall, the hand space analysis shows a simpler and clearer picture, providing evidence that distance and target width in hand space affect the spatiotemporal characteristics of pointing movements. This suggests that, for pointing devices like a mouse or tablet, analysis and modelling can be done more effectively by considering the hand actions required for a task, regardless of the scale of the display.

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