Card, English, and Burr (1978) – 25 Years Later

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ABSTRACT
We revisit the Fitts' law model published 25 years ago by Card, English, and Burr. Their research was important because it was the first comparative evaluation of the mouse, and also the first use of Fitts' law in HCI. For the mouse, they reported *MT* = 1.03 + 0.096 *ID*, with *throughput* as the slope reciprocal: *TP* = 1 / 0.96 = 10.3 bps. We re-analysed their data in view of ISO9241-9, the new standard for pointing devices. The reanalysis yields a throughput of 2.65 bps, or 4.32 bps including a nominal adjustment for the time for the hand to grasp the mouse.

Keywords
Fitts' law, pointing devices, throughput, ISO9241-9

INTRODUCTION
Twenty-five years ago Card, English, and Burr published a seminal paper [1] comparing four methods of selecting text on a CRT display. One test condition was the mouse. Their paper was important for several reasons. For one, it was the first comparative evaluation of this new input device destined to transform the way humans interact with computers. Second, it was the first use of Fitts' law in HCI. Important also was their implicit call to harden the science in this emerging field. Their call was echoed in subsequent publications [8], and, today, models, theories, and empirical methods are the hallmark of quality research in HCI.

This short paper revisits a central theme in Card et al.'s paper: the Fitts' law analysis of the mouse. We update their analysis in light of current practice, particularly in view of the new ISO standard for evaluating pointing devices [3].

FITTS' LAW – IN BRIEF
Fitts' law is a model of human movement derived by analogy from Shannon's theory of communications [2, 5]. It is both predictive and descriptive. As a predictive model, it is a linear equation for the movement time (*MT*) to select a target given the *index of difficulty* (*ID*) of the task:

$$MT = a + b\,ID \tag{1}$$

The predictive form of the model has various applications; e.g., a priori analyses of soft keyboards layouts [7].

As a descriptive model, Fitts' law provides a summary performance measure of a device-task condition. This is Fitts' *index of performance* – now called *throughput* (*TP*):

$$TP = ID\,/\,MT \tag{2}$$

Interestingly, both eq. 2 and 1/*b* in eq. 1 have units *bits/second*. While 1/*b* is frequently cited as throughput, eq. 2 is used in ISO9241-9. It is also the equation proposed by Fitts [2, p. 388].

The formulation for *ID* in ISO9241-9 is

$$ID = \log_2(A\,/\,W_e + 1) \tag{3}$$

where *A* and W are the movement amplitude and width. With the subscript "e", *W* is the *effective target width* and includes an adjustment for accuracy. *TP* so computed reflects speed *and* accuracy – worthwhile indeed.

METHODOLOGY
Card et al.'s experiment used a point-select task. Participants began each trial by pressing the space bar and then acquiring the pointing device with the same hand. They manoeuvred the cursor and selected targets consisting of highlighted text on a display. There were five target amplitudes (1, 2, 4, 8, 16 cm) and four target widths (1, 2, 4, 10 char). Characters were 0.246 cm wide and 0.456 cm high. The 20 target conditions yielded 12 unique *ID*s. The analysis was presented in a scatter plot [1, fig. 6] and regression line:

$$MT = 1.03 + 0.096\,ID \tag{4}$$

with throughput reported as

$$TP = 1\,/\,0.096 = 10.3\text{ bps} \tag{5}$$

This value is substantially higher than those in ISO-conforming evaluations using a mouse, where there is a coalescing of *TP* values for the mouse in the range of 4-5 bps. (Space precludes a detailed review, but see [4] for a recent representative example.)

Card el al.'s calculation of *TP* differed from current practice in at least four ways:

CHI 2003, April 5-10, 2003, Ft. Lauderdale, Florida, USA.
ACM 1-58113-637-4/03/0004

TP Calculation	Card et al.	Current Practice
Target width in 2D	W	Smaller of W or H
ID formula	$\log_2(A/W + .05)$	$\log_2(A/W_e + 1)$
Treatment of errors	Error trials excluded	*ID* adjusted for errors
TP formula	$TP = 1/b$	$TP = ID / MT$

In the following section we revisit Card et al.'s analysis, updating their *TP* calculation, as per current practice.

SUMMARY TABLE AND ANALYSIS

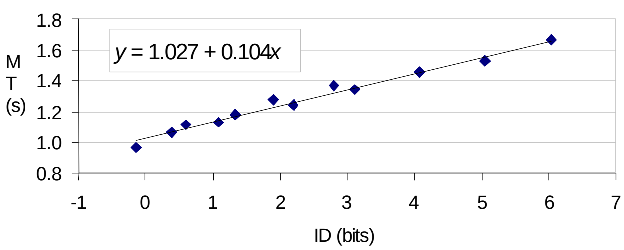
Table 1 is a reverse-engineered summary table for the data in Card et al.'s scatter plot.

Table 1

A (cm)	*W* (char)	W_{1D} (cm)	ID^a (bits)	W_{2D} (cm)	ID^b (bits)	*MT* (s)	*TP* (bps)
1	10	2.46	-0.14	0.456	1.67	0.97	1.73
2	10	2.46	0.39	0.456	2.43	1.06	2.28
4	10	2.46	1.09	0.456	3.29	1.13	2.91
8	10	2.46	1.91	0.456	4.21	1.27	3.31
16	10	2.46	2.81	0.456	5.17	1.37	3.77
1	4	0.984	0.60	0.456	1.67	1.11	1.50
2	4	0.984	1.34	0.456	2.43	1.18	2.06
4	4	0.984	2.19	0.456	3.29	1.24	2.65
8	4	0.984	3.11	0.456	4.21	1.34	3.15
16	4	0.984	4.07	0.456	5.17	1.45	3.56
1	2	0.492	1.34	0.456	1.67	1.18	1.42
2	2	0.492	2.19	0.456	2.43	1.24	1.96
4	2	0.492	3.11	0.456	3.29	1.34	2.46
8	2	0.492	4.07	0.456	4.21	1.45	2.90
16	2	0.492	5.05	0.456	5.17	1.53	3.38
1	1	0.246	2.19	0.246	2.34	1.24	1.88
2	1	0.246	3.11	0.246	3.19	1.34	2.38
4	1	0.246	4.07	0.246	4.11	1.45	2.83
8	1	0.246	5.05	0.246	5.07	1.53	3.31
16	1	0.246	6.03	0.246	6.05	1.66	3.64
						mean:	2.65

[a] $ID = \log_2(A / W_{1D} + 0.5)$ (Welford formulation)
[b] $ID = \log_2(A / W_{2D} + 1)$ (Shannon formulation)

The left four columns can be determined definitively from their paper. Although *MT* (col. 7) was measured by ruler, the values are reasonable given the similarity of the figure and equation below to the originals. The difference is just 0.003 s for the intercept and 0.008 s/bit for the slope.



Target width in 2D. Card, English and Burr interpreted target width as the horizontal extent of the targets. The 5th and 6th columns recalculate *ID* using the smaller of the target's width and height as *W*. The rationale is that for rectangular targets selected in 2D, the smaller dimension is more indicative of the accuracy demands of the task [6].

***ID* formula**. *ID* was measured using the Welford formulation, whereas ISO9241-9 uses the Shannon formulation (Table 1 footnotes). Among the benefits in the latter is that *ID* cannot be negative. So the easiest task changes from -0.14 bits to 1.67 bits (Table 1 top row).

Treatment of errors. Although Card et al. reported an error rate of 5% for the mouse condition, their Fitts' law model excluded error trials [1, p. 605]. This precludes a post hoc adjustment for accuracy.

***TP* formula**. Throughput is computed in ISO9241-9 by directly dividing *ID* by *MT*. The effect is seen in the right-hand column of Table 1. *TP* ranges from 1.42 to 3.77 bps with a mean of 2.65 bps.

DISCUSSION

The difference between the original (10.3 bps) and revised (2.65 bps) throughputs is substantial. Although a key factor is the method of calculation (see above), an additional issue is the high intercept in their regression line. Card et al. offered two reasons for this: the time to grasp the mouse at the beginning of a move, and the time for the final button click [1, p. 608]. No systematic effect of button clicks on the intercept appears in the literature (e.g., positive and negative intercepts are both common; see [5]), so this explanation is discounted. However, if a trial began with the initial mouse motion, grasping time is a candidate for the large intercept. Aguably, this time should be excluded. Doing so by reducing each *MT* in Table 1 by, nominally, 0.5 s increases throughput to 4.32 bps, a value typical in ISO-conforming studies for the mouse.

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