The Calculator

How can product designs accommodate Fitts' law?

Have a look at the calculator illustrated in figure 3.1*a*. It is a pretty simple layout—not too many keys to get you confused, all are nicely labeled, the display is clear, and so on. But, from a motor control point of view, the layout suffers from a simple design error: all of the keys, regardless of their frequency of use, are the same size. Why does the 1/x key (which I have never used) need to be as large as the = (Enter) key, which I use on every calculation? In the calculator shown in figure 3.1*b*, I tripled the width of the enter key simply by removing a couple of keys that I never use. The new design should allow me to work faster with less chance of hitting the wrong key. The modification reflects an important concept in motor control: the speed–accuracy trade-off.

Paul Fitts was a pioneer in the study of motor control. His early work involved the study of errors made by pilots during World War II, and he was particularly interested in understanding the speed–accuracy trade-off in various situations. Fitts found that two components of aimed hand movements were primarily responsible for their speed and accuracy. One

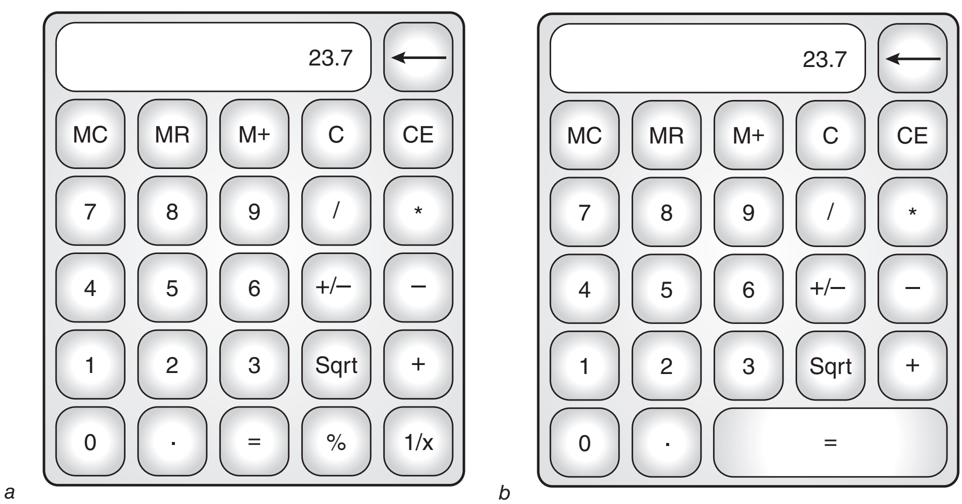

Figure 3.1 Compare these two calculators. In (*a*), all the keys are the same size. In (*b*), I have removed some keys that I use rarely and increased the size of the Enter key (which I use often). The rationale is based on Fitts' law.

component was the distance required for the hand to travel from its starting point to the target. The other component was the size of the target. In other words, Fitts studied movements that differed in terms of how far the hand needed to move and how much tolerance there was for missing the target once the hand got there. He studied these two components under various contrived experimental conditions that he could control and manipulate with precision, such as moving a penlike stylus back and forth between two rectangular targets, inserting pins into holes, and fitting washers onto pegs, taking extreme care to systematically vary the sizes of each item.

Fitts told his participants to try very hard never to miss the targets and examined how they altered their movement times to comply with that instruction. He found that movement time increased by a constant amount whenever the distance to move doubled or whenever the size of the target was reduced by half. In a typical Fitts-type experiment, the average speed to perform hand movements under various combinations of distance and size is usually plotted on a graph using average movement time along the ordinate (vertical axis). For the abscissa (horizontal axis), Fitts devised a clever measure of the combined difficulty of the task requirements using a logarithm to the base (2) of the distance and target size (because each successive data point represents an increase of twice the distance or half the size). Fitts referred to this measure as the index of difficulty, which is simply

$$\mathrm{ID} = \log_2(2D/W)$$

in which ID refers to the index of difficulty, D is the distance to travel from the home position to the target (or from one target to another target), and W is the width of the target(s).

Experiments conducted by Fitts, and replicated many times since, revealed that movement time was a straightforward result of the effects of a task's index of difficulty. In fact, the results were so repeatable and generalizable that the finding has since become known as Fitts' law. Formally, Fitts' law is expressed as follows:

$$\text{Movement Time} = a + b\,(\mathrm{ID})$$

This formula is nothing more than a variation of a simple linear equation ($y = a + bx$). In Fitts' law, y is replaced by movement time (MT); a is the expected movement time when $x = 0$ (e.g., in the tapping version of the Fitts' task this would be a situation in which the subject is tapping up and down with no endpoint accuracy requirement); b is the slope, or the constant increment in movement time whenever x is increased by one unit; and x is replaced by ID, which refers to the index of difficulty, as defined previously.

In the typical Fitts tapping task, a person is asked to move back and forth as fast as possible between two targets, stopping only long enough to tap down on a small metal plate, and continues this repetitive back-and-forth tapping for a period of time, such as 20 seconds. The number of taps is counted, and this value is then divided into 20 to calculate the average movement time per tap. Many trials are conducted to examine various permutations of the task that are made by varying the size of the targets and the distance between them. In the end, the data are summarized and illustrated as in the graph in figure 3.2.

The data represented by the squares and circles in the graph could be from two different people, or they could represent average group data from two different age groups, or they might represent data using two different computer input devices—say, moving a cursor on a screen with a mouse versus a finger touchpad. It really doesn't matter what the two sets of data points represent. Rather, the linear equations represented by the letters A and B in figure 3.2 indicate that A involves a slower system: system A has a slope of 50, and system B has a slope of 40. This simply means that whenever the index of task difficulty is increased by 1 (i.e., by doubling the distance or halving the target width), movement time is expected to increase by a constant amount that is equal to the slope (40 or 50 msec for B and A, respectively). Because the increase is larger for A than for B, system A must be slower than system B, because its processing speed requires more time for each additional increase in the ID.

The Fitts task is a specific version of the speed–accuracy trade-off because it places constraints on the user *not* to make an error. To comply with that requirement, the user must slow down when the task becomes more difficult. Note that A and B in the graph in figure 3.2 could also represent the calculators in figure 3.1. Because the Enter key for the calculator in

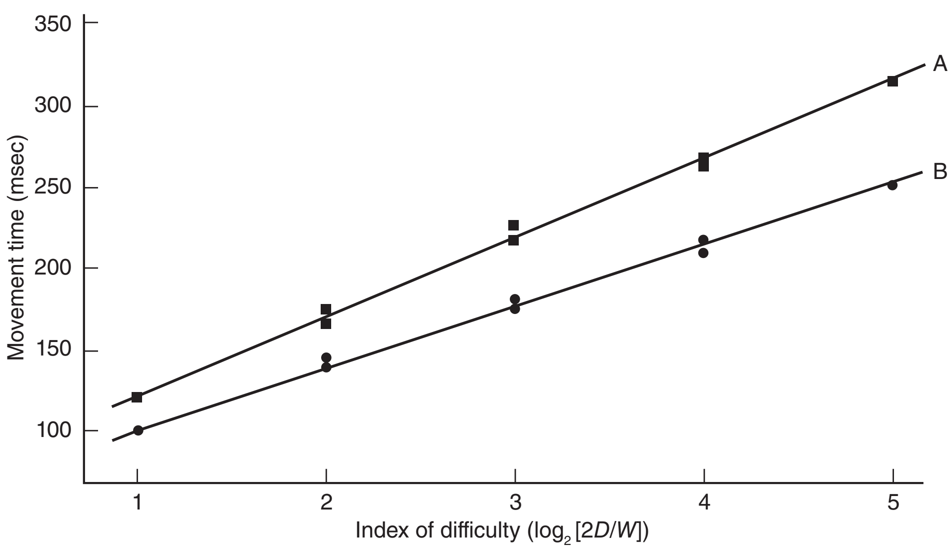

Figure 3.2 Sample graph from a Fitts-type experiment. The lines denoted by A and B could represent different people or systems. The steeper slope in line A denotes a slower processing system.

figure 3.1*a* is smaller than that in figure 3.1*b*, its operator must move slower than the operator using the calculator in figure 3.1*b* to maintain the same error rate.

So, given our knowledge of Fitts' law and how it affects the speed–accuracy trade-off in rapid aiming, could we use it to our advantage to enhance performance? In other words, can we *beat* Fitts' law? The calculator example given in figure 3.1 was a simple illustration. By removing a couple of infrequently used keys and increasing the size of the key used most often, I have dramatically improved performance by increasing the overall speed of making calculations while at the same time reducing the probability of making errors.

Other examples of beating Fitts' law are all around you. Here are two. The Apple Macintosh computer desktop has icons that that get larger as you approach them. This makes them faster to acquire and reduces the chance of clicking an unwanted icon and opening an application by mistake. The expanding sizes allow the user to move faster without increasing the error rate. An example of something that falls prey to Fitts' law is the typical computer drop-down menu. Compare the linear and circular (or pie) menus in figure 3.3. From the starting point denoted by the dot in each figure, you can see that the distance to reach each successive choice (from one to eight) gets progressively farther in the linear menu. However, with a central starting position in the circular (or pie) menu, each choice is equidistant. The pie menu and the expanding icons used on the Apple Macintosh provide nice illustrations of how the target size and distance components of Fitts' law can be overcome with a little ingenuity.

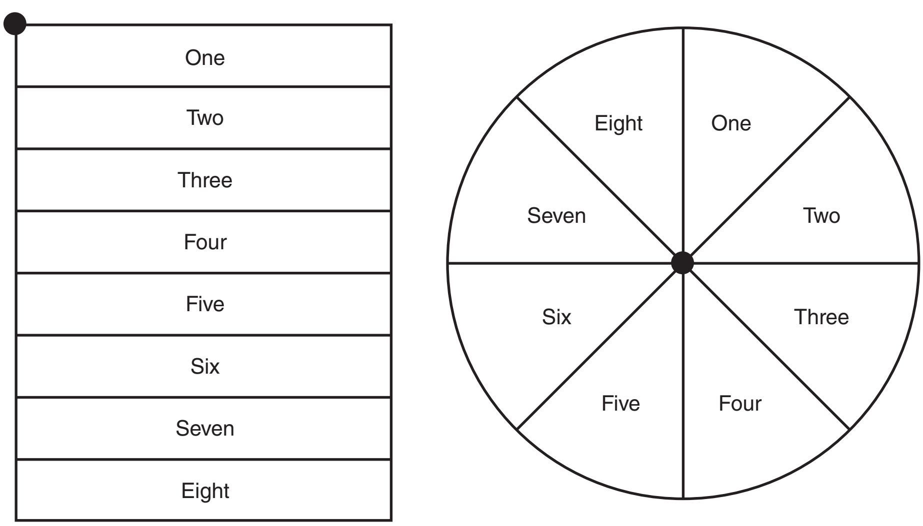

Figure 3.3 Circular (pie) drop-down menus reduce the speed of accessing a specific icon compared to linear menus. This is one way to beat Fitts' law.

Self-Directed Learning Activities

1. Define *Fitts' law* in your own words.
2. There are several different ways in which speed and accuracy are traded in order to achieve a desired motor performance. Describe in your own words which specific version of the speed–accuracy trade-off is addressed in Fitts' law.
3. Describe another application (such as redesigning the calculator keypad or reshaping computer menus) in which you could use the understanding gained from Fitts' law to improve movement times, reduce aiming errors, or both.
4. Sketch combinations of targets and starting positions that correspond with IDs of 1, 2, 3, 4, and 5, according to Fitts' law (use appropriate combinations of target distance and width), and conduct a Fitts-type experiment, reporting the results as in figure 3.2.

Notes

- Logarithms to the base 2 ($\log_2$) are not difficult to compute. For example, the $\log_2$ of 8 is 3—it is simply the number to which the base 2 must be raised to achieve the target number. In this case, 2 must be raised to the power of 3 to reach 8 ($2^3 = 8$).
- Take note in figure 3.2 that there are two squares and two circles for A and B corresponding to ID levels of 2, 3, and 4. For example, a task with a distance of 4 centimeters and a target size of 1 centimeter would have an ID of 3 because the $\log_2$ of $(2 \times 4 / 1)$ is 3. However, another target combination in which the distance is twice as far (8 cm) but the target is also proportionally larger by the same amount (twice as wide—doubling the target width from 1 cm to 2 cm, in this case), would also have the same ID because the $\log_2$ of $(2 \times 8 / 2)$ is also 3.

Suggested Readings

Fitts, P.M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology, 47,* 381-391.

Schmidt, R.A., & Lee, T.D. (2011). Principles of speed and accuracy. In *Motor control and learning: A behavioral emphasis* (5th ed., pp. 223-262) Champaign, IL: Human Kinetics.

From T.D. Lee, 2011, *Motor control in everyday actions* (Champaign, IL: Human Kinetics).