Comment on “Visual layout modulates Fitts’s law: The importance of first and last positions”

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Abstract Pratt, Adam, and Fischer (2007) investigated the effect of surrounding targets on the time it took to move to an individual target and found that the movement time to a central target was above the Fitts’s law line related to the first and last targets. They explained their results in terms of a “visuomotor hypothesis.” Here, an alternative explanation is given in terms of a previously validated model of the “available target width” that is determined by the size of the target and the width of the finger pad that is being used to hit the target.

Keywords Fitts’ law · Available target width · Multiple targets

Introduction

The experiment of Pratt, Adam, and Fischer (2007)

Pratt et al. (2007) used the experimental arrangement shown in Fig. 1 (extracted from their article), with targets presented on a touch screen and the finger used as the test probe (a stylus was not used). The authors measured reaction and movement times to each of the targets, with the aim of finding the difference due to the “placeholder effect” of a

structured visual array of targets. In such an array, the first and last of the targets had less spatial constraint on aiming at the target, as compared with a center target, where there was constraint on both sides of the target. Targets were always squares 11.2 mm on a side and spaced 17 mm apart (center to center), with an initial distance of 168 mm for set 1, 185 mm for set 2, and 202 mm for set 3. Fitts’s index of difficulty (*ID*), defined as $ID = \log_2(2A/W)$, had the values shown in Fig. 1, ranging from 4.90 to 5.39 (here, *A* is the amplitude of the movement, and *W* is the target width). According to the criterion developed by Gan and Hoffmann (1988), all movements should have required visual control.

Pratt et al. (2007) obtained the results shown in Fig. 2. Here, the first and last data points of each set lay along a single line described by Fitts’s law, but the data for the middle targets, which also fell on a straight line, were above those for the first and last data points. Pratt et al. presented measures of “effective target width,” being the width containing 96% of the hits on the target. It was not stated how these were obtained, but presumably, they were obtained from the first touch-point of the finger on the touchpad. There was no significant difference between the sizes of the effective target widths for any of the test conditions, but there was a trend for the center targets to have smaller effective target widths than for the first and last target locations. This trend might be expected, due to the lower level of constraint on the first and last targets.

Adam, Mol, Pratt, and Fischer (2006), in a prior experiment, found that final locations in arrays have special status, perhaps acting as spatial anchoring points. Pratt et al. (2007, p. 353) also noted that “the relative position of a target in a structured perceptual array can affect the speed–accuracy trade-off function described by Fitts’ law.”

Pratt et al. (2007, p. 354) discussed two different reasons for why the first and last positions in an array of placeholders produce such an effect on the speed–accuracy

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Fig. 1 Experimental layout of targets used by Pratt, Adam, and Fischer (2007). Numerical values are the indexes of difficulty of each target location

trade-off. The first is a perceptual account that they felt was inadequate. The second possibility is that movements are easier to control when in the end positions “because the borders of objects act as particularly salient visual landmarks that enable participants to home in on the target with fewer corrections.”

On the basis of the suggestion that a visuomotor hypothesis may explain the results, Pratt et al. (2007, p. 354) stated, “It now seems unlikely that a single equation will be able to accurately capture all aspects of speed–accuracy tradeoffs, and existing models of motor control will need to be examined, reinterpreted, or possibly replaced.”

In the following, a model developed for movement times on keypads, which are an array of targets similar to those

Fig. 2 Data in Pratt, Adam, and Fischer (2007) showing the effect of placement of the target on movement times to first, second, and third targets within the group

studied by Pratt et al. (2007), is used to show that a single explanation can be given for the movement time data for *all* target locations. It appears that, with the correct interpretation of the available target sizes, all data will lie along a single line described by Fitts’s law.

The model of Drury and Hoffmann (1992)

Drury (1975) originally developed a model for available target size when a foot is moved between targets. In this model, the criterion for hitting the target was that any part of the foot should contact any part of the pedal, as in using a foot brake in an automobile. Thus, simple geometry shows that the available target size is the sum of the actual target size plus the width of the shoe. This model was validated by Hoffmann (1991) using an “inverted” Fitts’s task and by Hoffmann and Sheikh (1991) when studying finger width corrections, using the finger as a probe in a Fitts’s paradigm.

Drury extended this model (Drury & Hoffmann, 1992) to the case of movements on keypads, where a successful key acquisition means that the target key is hit, while adjacent keys are not hit. The authors showed that two cases need to be considered when a target that is within an array is aimed at. With S being the target center spacing, W the target size, and F the finger pad width, the two cases for the available target width are the following:

- (i) Limited by missing the target key (clearance between keys $>$ finger pad width):

$$W_{avail} = W + F. \quad (1)$$

- (ii) Limited by hitting adjacent keys (finger pad width $>$ clearance between keys):

$$W_{avail} = 2S - W - F. \quad (2)$$

The model was also validated by Hoffmann, Tsang, and Mu (1995) when subjects moved to keys within a large array.

The present case of the Pratt et al. (2007) data is different for the first and last targets, since there was no constraining target on one side of these targets. In the Pratt et al. study, the distance between adjacent targets ($17 - 11.2 = 5.8$ mm) was smaller than any reasonable finger width (see below for finger width discussion). Therefore, we have constraint on one side related to (i) above and on the other side of the target by (ii) above. Hence, the available target size in that case is given by the following (see the Appendix):

$$W_{avail} = S. \quad (3)$$

The aim of the present comment is to show that a very simple explanation can be given for the effect of target

placement within a group of targets, in terms of the model developed by Drury and Hoffmann (1992) for the movement time to an array of keys on a data entry keypad. As in the case of data entry, the task in Pratt et al. (2007) has constraint placed on the movement by the adjacent targets, and consequently, the data may also be described by the Drury model. We are, in effect, assuming that Fitts's law is valid for the Pratt et al. data and determining the finger pad width that would best correlate the data in terms of Fitts's law. It will be shown that, contrary to the statement of Pratt et al., a single equation can be found to accurately describe the data of their experiment.

Reanalysis of the Pratt et al. (2007) data

Data were scaled from the data shown in Fig. 2 in the Pratt et al. (2007) article. These are shown in Fig. 2 of the present article. The figure shows three clear sets of data. These correspond, going from left to right, to the three sets of conditions, labeled sets 1, 2, and 3, for different amplitudes and indices of difficulty of the target shown in Fig. 1. The interesting feature of the movement times is that the first and the last targets within a set are lower than would be expected from Fitts's law encompassing the three data points for each condition. Alternatively, this may be viewed as the middle target within a set having a higher movement time than might be expected.

The problem is how this is to be explained. Pratt et al. (2007) found that the first and last points in each data set lay along a single line described by Fitts's law. The middle data points also describe a line that is higher than for the first and last positions within the set. On this basis, and according to the model of Drury and Hoffmann (1992), the available target size for the first and last targets should be identical. The available target size for the middle target will be less, as described by the Drury and Hoffmann model, since the movement times are higher. According to the model, the available target size for the first and last targets will be, by Eq. 3,

$$W_{avail} = S = 17 \text{ mm},$$

and for the central targets, by Eq. 2,

$$W_{avail} = 2S - W - F = 2 \times 17 - 11.2 - F = 22.8 - F \text{ mm},$$

where 17 (mm) is the center-to-center distance of the targets, 11.2 (mm) is the target size, and F is an assumed finger pad size (mm).

The finger pad size is not simple to measure, since the flesh and skin are soft. Drury and Hoffmann (1992) discussed finger width and found it to be within the range

of 8.4–11.7 mm, with a mean value of 10.1 mm for their 10 participants. Their best estimate came from assuming different finger widths and finding the maximum r^2 in the regression of movement time against available width. This procedure gave a mean finger pad size of 8.2 mm. Hoffmann et al. (1995) measured finger pad sizes statically, using a light press, and found a mean value of 10.7 mm. However, when measures were made dynamically, with subjects making reciprocal movements, the mean pad size was 7.6 mm. Hoffmann and Sheikh (1991), using a static test with light pressure, found a pad width of 10.2 mm. For the Pratt et al. (2007) data, we again carried out regressions to determine the correlation of movement time with the ID based on an assumed finger pad width. Here, the ID was defined as

$$ID_{avail} = \log_2(2A/W_{avail}),$$

where A is the amplitude of the movement.

Using these definitions for the available target sizes, and assuming a wide range of finger pad sizes (7–15 mm), the resulting r^2 between movement time and the effective ID is shown in Fig. 3. The best fit is obtained with a finger pad size of 8 mm, which is in the range measured in previous research. The resulting relationship, shown in Fig. 4, is given by

$$MT = 50.8 + 76.3 ID_{avail}; \quad r^2 = .985.$$

Discussion

It does not appear necessary, at least in this data set, to make complex arguments about the reason for the change in movement time when there are adjacent targets. The data in Pratt et al. (2007) can be modeled purely in terms of an ID based on an “available target size,” as defined by Drury and Hoffmann (1992). This is not to say that there is no

Fig. 3 Effect of assumed finger pad width on the correlation between movement time and the index of difficulty, taking into account the “available” target width

Fig. 4 Movement time (in milliseconds) as a function of the index of difficulty based on available target width, with an assumed finger pad width of 8 mm

“visuomotor” effect, as was suggested by Pratt et al. In order to determine whether such an effect exists, however, it is necessary for an experiment to be carried out in which one or more of the following designs are used:

1. Use a pointed probe, so that the effects of using a probe of finite width are eliminated.
2. Place targets within the array that have less constraint than others, rather than just in the first and last positions.
3. Use targets having different sizes and intertarget distances, so that the constraint is varied from zero to a very tight form in which the subject is forced to work very accurately in order to miss adjacent targets.

In any experiments using Fitts’s law, it will be necessary to ensure that the *ID* values are sufficiently large to ensure visually controlled movements.

The value of finger pad width that gives a best fit to the regression of the data (8 mm) is within the range that has been measured statically and dynamically by various researchers. It is, however, very difficult to obtain an exact measure, since the dynamic value will be different from the static value, due to differences in hand posture and applied pressure that may arise in static and dynamic tests.

The important result of this reanalysis of the data of Pratt et al. (2007) is that Fitts’s law is again found to be valid where visual control is required in making the movement: There is no “modulation” due to the visual array of targets. As has been found in some other studies of Fitts’s law, modifications have had to be made to accommodate the experimental constraints. Another example of where an appropriate target size is used is the case of moving targets (Hoffmann, 1991), where the dynamic lag in the system has an effect on the available target size.

The results of Adam et al.’s (2006) experiment also show a reduced movement time for the final target in both

their Experiments 1 and 2, but a reduced time for the first target only in Experiment 2. A similar analysis of their Experiment 2 data requires a finger pad width of about 9 mm, which is consistent with our reanalysis of the data in Pratt et al. (2007).

Where does this reanalysis leave the concept of modulation of Fitts’s law by the visual array of targets in which the target aimed at is embedded? We cannot be sure that the reanalysis completely eliminates the possibility of the concept; however, under the experimental conditions used by Pratt et al. (2007), we cannot see any strong support for the concept. As was noted above, only with further experiments in which the spacing of targets within the array is varied or a pointed probe is used can a true evaluation of the concept be made.

Conclusions

The model of Drury, which has been found to accurately describe visually controlled movement times on data entry keypads, gives an excellent description of data for the present case. Fitts’s law holds in this modified form in which the constraints placed on the accuracy phase of the movement are considered by means of the “available” target size.

In any further experiments, it will be necessary to measure finger pad width using the same hand posture and the same contact pressure as those used in movements. Also, target constraints within the array need to be varied to obtain a true test of the concept of modulation of Fitts’s law by the visual array.

Appendix: Calculation of available target width for first and last targets

1. Consider an array of targets of width W that are spaced at a distance S apart and have a clearance between the targets that is less than the finger or probe width. The distance between the inner edges of the adjacent targets is $(2S - W)$. Hence, the tolerance for the finger to hit the target, while missing adjacent targets, is $(2S - W - F)$. It is this tolerance, or available target width, that determines the value of the *ID* of the movement.
2. At the left-hand side of the last target, the available space is $(S - W)$, this being the space between adjacent targets. The right-hand side the target can be hit if the finger just touches the far right of the target. Hence, the space available is $(S - W) + (W + F)$, and from this value, the finger pad width must be subtracted to obtain the available tolerance. Hence, the available target width is

S , the center-to-center spacing of the targets. This applies to both the first and last targets in the three-target array used by Pratt et al. (2007).

References

- Adam, J. J., Mol, R., Pratt, J., & Fischer, M. H. (2006). Moving farther but faster; An exception to Fitts' law. *Psychological Science*, 17, 794–798.
- Drury, C. G. (1975). Application of Fitts' law to foot-pedal design. *Human Factors*, 17, 368–373.
- Drury, C. G., & Hoffmann, E. R. (1992). A model for movement time on data entry keyboards. *Ergonomics*, 35, 129–148.
- Gan, K.-C., & Hoffmann, E. R. (1988). Geometrical conditions for ballistic and visually-controlled movements. *Ergonomics*, 31, 829–839.
- Hoffmann, E. R. (1991). Capture of moving targets: A modification of Fitts' law. *Ergonomics*, 34, 211–220.
- Hoffmann, E. R., & Sheikh, I. H. (1991). Finger width corrections in Fitts' law: Implications for speed–accuracy research. *Journal of Motor Behaviour*, 23, 259–263.
- Hoffmann, E. R., Tsang, K. K., & Mu, A. (1995). Data-entry keyboard geometry and keying movement times. *Ergonomics*, 38, 940–950.
- Pratt, J., Adam, J. J., & Fischer, M. H. (2007). Visual layout modulates Fitts's law: The importance of first and last positions. *Psychonomic Bulletin & Review*, 14, 350–355.