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THE MOVEMENT OF THE HAND TOWARDS A TARGET

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Previous work on the approach trajectories of hands to targets in tracking and aiming tasks had produced contradictory evidence about the shape of these curves. This paper shows that these trajectories are a function of the level of practice of the subject; an interpretation in terms of the theory of intermittent control of movements is advanced. Previous contradictory data can be resolved by reference to the subjects' level of practice. In addition, this theory will encompass the differences between accurate and free movement trajectories reported earlier.

Introduction

A considerable body of data on the movement of a hand towards a target of some sort has been gathered. Woodworth (1899) distinguished an acceleration phase, a central phase of uniform velocity and a deceleration phase in movements of this type. Slower movements tended to have much longer deceleration phases, as did movements requiring accurate termination. Peters and Wenborne (1936) also found that the sizes of the acceleration and deceleration phases were dependent on the length of the movement, and the terminal precision required of the subject. Lowry, Maynard and Stegmerten (1948) claimed that approach curves showed a period of constant velocity. Taylor (1947) and Taylor and Birmingham (1948), using an oscilloscope and joystick technique, displayed position, velocity, acceleration and rate of change of acceleration on four separate oscilloscopes. They found:

(a) there was no period of constant velocity in approach movements;
(b) the relative sizes of the acceleration and deceleration phases depended on terminal accuracy: accurate movements tended to have longer deceleration phases, while movements of an approximate extent only had symmetrical patterns;
(c) when movement distance was increased, all the movement parameters increased in value, but quickly reached an asymptote as muscle forces reached their maximum;
(d) There were small variations in velocity and acceleration during the two main phases.

Vince (1948) confirmed the two phase nature of accurate movements in tracking tasks, with the deceleration phase of longer duration. Annett, Golby and Kay (1958) with their well-known high speed film technique found that most of the movement time was spent close to the target; they considered the approach as occurring in two distinct parts, a fast gross movement to the target area, followed by a slow terminal phase.

Murrell and Entwisle (1960) showed that approaches to targets were of a complex nature with changes in velocity during the main acceleration and deceleration phases. They suggested this was tremor: they found acceleration to occupy about one third of the movement time. Crossman and Goodeve (1963) also found irregularity in approach curves; they suggested that this was evidence for corrective responses. They also confirmed earlier work on accurate and "free" movements. Edwards (1965) showed that no period of constant velocity occurred, but confirmed that deceleration took longer than acceleration.

These workers used many sorts of task, including line drawing, aiming, step-tracking, joystick control, wrist rotation, and repetitive tapping. The results can thus be considered fairly general for approach movements. No particular use of this knowledge had been considered until Howarth, Beggs and Bowden (1971) measured the approach of the hand to a target with some accuracy. They used naive subjects, and found an almost symmetrical sigmoid relating time and distance to impact.

Beggs and Howarth (1972) also measured the approach curves of subjects who suffered interruption to their vision during aiming, and showed again almost symmetrical approach curves. From their theory of intermittent feed-back control of movement, they showed that terminal accuracy depended on the distance to impact, d_u, at which a final corrective movement could be applied to the movement, for both groups of subjects (Howarth *et al.*, 1971; Beggs and Howarth, 1972).

However, these naive subjects had apparently symmetrical approach curves, which is a contradictory result to the majority of previous experiments. The symmetry was both in the sizes of two main phases of movement and in the regularity across movement speed.

The main differences between these experiments and earlier work was the use of naive subjects and paced movements. In this paper, data on paced movement will again be reported. Initially, a naive subject was used, but given extended practice on an aiming task. This was monitored and the changes in approach to the target will be described.

Materials and Method

The apparatus used has been described in detail in Howarth *et al.* (1971). The movement made was similar to dart throwing; a pencil held in the normal fashion was moved from a home position near the subject's right shoulder to the vertically mounted target in front of the home position. The subject successively hit the base-plate and target coincident with metronome ticks: the movement distance was 508 mm.

A moveable infra-red beam which fell on a photocell was broken by the subject making repetitive movements to the target. This beam started a timer, which was stopped by the subject hitting the target. The infra-red beam and photo cell were placed at 10 equal intermediate distances between the baseplate and target.

Paper targets were used, and the subject was instructed to be accurate. Terminal accuracy was measured from the distribution of pencil marks around the vertical target line drawn on millimetre graph paper.

One subject was used for this experiment. She was an undergraduate psychology student, with corrected-to-normal vision. She took part on four successive days.

During each of the training sessions she performed 30 trials of 20 shots at the target. Three speeds were used, being 42, 85 and 125 ticks/min of a metronome or 1,425, 740 and 480 ms duration, at each of the 10 beam positions; these were presented randomly.

Results

These are shown in Tables I and II and in Figures 1, 2, 3 and 4. Successive sessions have been designated a, b, c and d.

TABLE I

Values of time to impact (ms) for different distances to impact, at three speeds and four levels of practice

Sessions		a			b			c			d		
Speed in t.p.m.		40	85	125	40	85	125	40	85	125	40	85	125
	0	0	0	0	0	0	0	0	0	0	0	0	0
	50·8	135	88	68	371	119	72	382	170	77	549	192	79
	101·2	255	153	100	467	196	108	507	260	135	662	326	160
	152·4	410	288	135	462	264	146	569	311	157	664	356	185
Distance	203·2	515	256	172	544	323	182	668	367	182	713	370	231
(mm)	254·0	637	297	194	629	359	192	729	372	222	808	409	240
	304·8	735	340	231	755	391	244	789	403	256	850	436	272
	355·6	728	374	281	829	428	270	865	442	292	976	492	304
	405·4	875	424	298	891	460	290	924	484	319	1015	497	316
	457·2	972	483	333	951	499	331	992	519	352	1026	528	370
	508·0	1425	740	480	1425	740	480	1425	740	480	1425	740	480

TABLE II

Values of mean square error in mm², and d_u *in mm² at three speeds and four levels of practice*

Speed in	a		b		c		d	
t.p.m.	E^2	d_u^2	E^2	d_u^2	E^2	d_u^2	E^2	d_u^2
40	2·27	11,653	2·00	1,008	1·35	645	1·08	413
85	11·85	57,006	8·60	30,272	3·73	16,129	3·35	7,458
125	19·12	158,014	13·43	153,006	16·83	137,522	7·61	115,845

On Figures 1, 2 and 3 is indicated the corrective reaction time of 290 ms as found by Beggs and Howarth (1970): in terms of their theory, corrections cannot be initiated after this time to impact.

Discussion

It is clear from inspection of Figures 1, 2 and 3 that the effect of practice is to change the shape of the approach curves to a target, both in the accelerative and particularly in the decelerative phase. We believe that the reason for this progressive change is that the subject was learning to minimize d_u, the distance through which the hand travels after the last corrective movement.

When naive, this subject had approach curves which were approximately symmetrical and did not vary in shape with movement time. This confirms our earlier work on naive subjects. However, as a result of practice she changed the shape of her approach curve so that she moved as close to the target as possible, as quickly as possible and then was able to spend more time on the terminal phase of the movement. This is obviously a more efficient strategy, and in terms of our

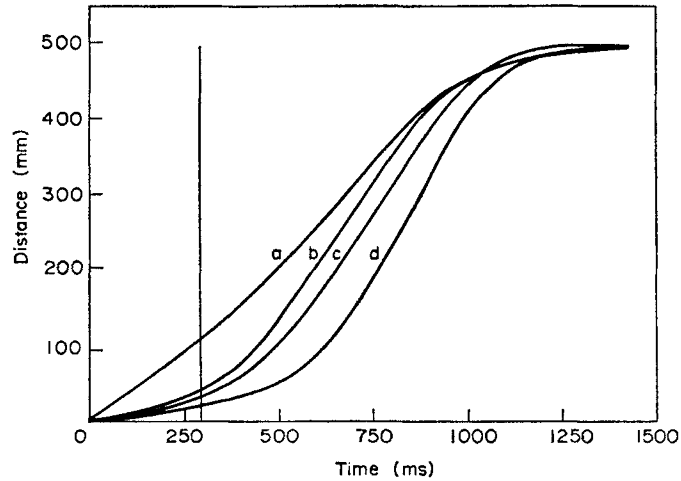

FIGURE 1. The smoothed relationship of distance to impact (d) and time to impact (t) for four levels of practice at 42 ticks per min.

theory, will reduce d_u to a smaller value than for the naive subject. At high speeds the approach curves of the practised subject are more symmetrical than at low speeds. This is presumably because of physical limitations on the acceleration and deceleration of the arm.

The apparent discrepancies in the literature on approach curves are easily resolved. All the studies which reported a change in the shape of the curve with speed used practised subjects. Our practised subject duplicated earlier results. Symmetrical curves are found for naive subjects or for free as opposed to aimed movement. For free movement it is not necessary to control the accuracy to any great extent so that there is no purpose in minimizing d_u. Symmetrical approach

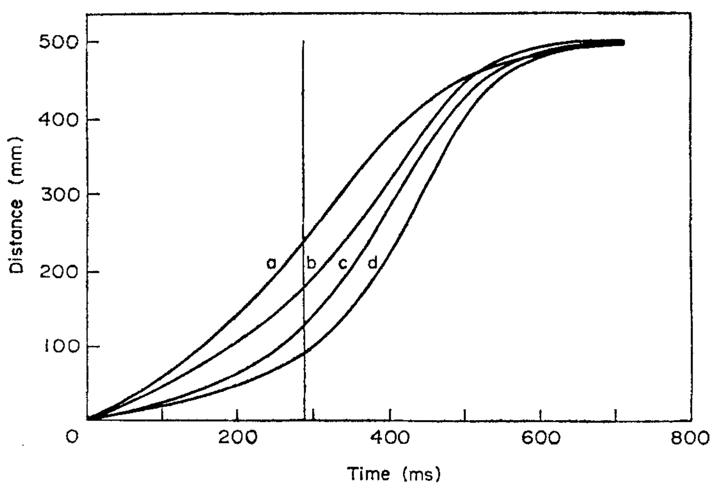

FIGURE 2. The smoothed relationship of distance to impact (d) and time to impact (t) for four levels of practice at 85 ticks per min.

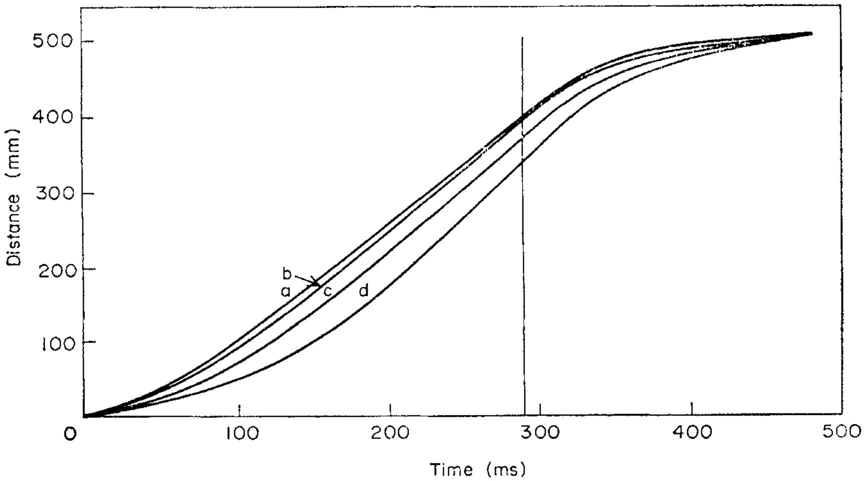

FIGURE 3. The smoothed relationship of distance to impact (d) and time to impact (t) for four levels of practice at 125 ticks per min.

curves are probably used because they minimize the muscle forces needed for a given extent of movement.

The effect of practice on accuracy provides an opportunity for a further test of our theory. The improvement in accuracy should be largely a result of the decrease in d_u, since error on target σ_ε should be predictable from the equation

$$\sigma_\varepsilon^2 = \sigma_0^2 + d_u^2\sigma_\theta^2 \tag{1}$$

where σ_0^2 is the tremor variance

σ_θ^2 is the variance in the angular error of aiming.

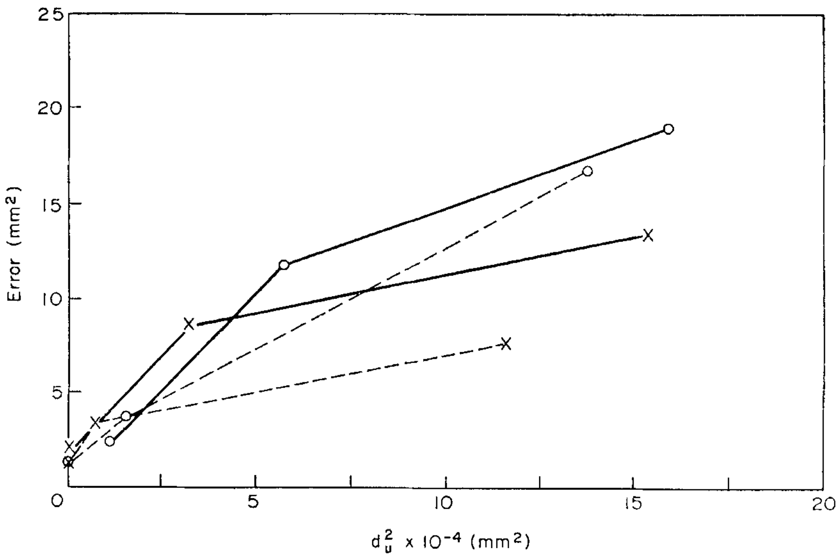

FIGURE 4. The relationship of error, in mm², to d_u^2, in mm² × 10^{-4}. ——○—— a; ——×—— b; – – – ○ – – – c; – – – × – – – d.

We have read off the values of d_u at each speed, and for each stage of practice, from the intercepts of the 290 ms line on Figures 1, 2 and 3. These values and the corresponding M.S. values of error have been fitted to this equation, and appear in Figure 4.

We have tended to assume that σ_θ is a constant for a given subject and a given movement. Figure 4 shows, however, that σ_θ decreased with practice, as well as d_u.

We believe the intercepts on the error axis, σ_0^2, to be measures of tremor. From Figure 4, it would seem that σ_0 has a value of about 1·6 mm for this subject, and remains fairly constant during practice. This could be expected if it were a physiological tremor component.

This is not a very elegant way in which to demonstrate our expected relationship between error and d_u; a better technique may clarify these effects of practice on σ_θ and σ_0^2.

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References

ANNETT, J., GOLBY, C. W. and KAY, H. (1958). The measurement of elements in an assembly task—the information output of the human motor system. *Quarterly Journal of Experimental Psychology*, **10**, 1–11.

BEGGS, W. D. A. and HOWARTH, C. I. (1970). Movement control in a repetitive motor task. *Nature*, **225**, 752–3.

BEGGS, W. D. A. and HOWARTH, C. I. (1972). The accuracy of aiming at a target—some further evidence for intermittent control. *Acta Psychologica*. (In press.)

CROSSMAN, E. R. F. W. and GOODEVE, P. J. (1963). Feedback control of hand-movement and Fitts' Law. Unpublished communication to Experimental Psychology Society, Oxford.

EDWARDS, E. (1965). Research note on the study of hand motions. *Perceptual and Motor Skills*, **20**, 1098.

HOWARTH, C. I., BEGGS, W. D. A. and BOWDEN, J. (1971). The relationship between speed and accuracy of movement aimed at a target. *Acta Psychologica*, **35**, 207–18.

LOWRY, S. M., MAYNARD, H. B. and STEGMERTEN, G. J. (1948). Reported in MURRELL, K. F. H. and ENTWISLE, D. G. (1960).

MURRELL, K. F. H. and ENTWISLE, D. G. (1960). Age difference in movement pattern. *Nature*, **185**, 948.

PETERS, W. and WENBORNE, A. A. (1936). The time pattern of voluntary movements. *British Journal of Psychology*, **26**, 388–406; **27**, 60–73.

TAYLOR, F. V. (1947). A study of the acceleration pattern of manual corrective responses. *American Psychologist*, **2**, 340.

TAYLOR, F. V. and BIRMINGHAM, H. P. (1948). Studies of tracking behavior, II. The acceleration pattern of quick manual corrective responses. *Journal of Experimental Psychology*, **38**, 783–95.

VINCE, M. A. (1948). Corrective movements in a pursuit task. *Quarterly Journal of Experimental Psychology*, **1**, 85–106.

WOODWORTH, R. S. (1899). The accuracy of voluntary movement. *Psychological Review Monograph Supplement*, **3**, 13.

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