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Effects of path angle changes on the times for ballistic and visually-controlled two-component arm movements

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ABSTRACT

Although several Predetermined Motion time Systems mention the effects of change of path angle during a movement, there does not appear to be any experimental evidence for the quoted effects. Here we report effects of angle changes between zero and 180° during the movement, with and without an intervening target at the end of the first component of the movement. The effects are variable: with ballistic movements without an intervening target there is an increase of MT with path angle change; when there is an intervening target the MT of the first component decreases with change of path angle, while that of the second component increases, so that the total movement time is independent of the change in path angle. When the movements are made under visual control, with no intervening target, MT increases with change of path angle, whereas when there is an intervening target, there is no effect of change of path angle, either on the first or second component of the movement. Thus the occurrence of movement time increments is dependent on the form of motor control and the way in which the path angle change occurs.

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Notation

The following notation was used for experiments with and without an intervening target, where relevant:

MT_1	movement time from starting position to intervening target (first component)
MT_2	movement time from intervening target to final target (second component)
A_1, A_2	amplitude of the first and second components of a movement
ID_1, ID_2	Index of Difficulty of first and second movement components
ID_{TOTAL}	ID based on the total movement distance when there is no intervening target
θ	change in path angle, measured from first component direction
DT	dwell time on first target in two-target sequence

1. Introduction

In performing manual tasks, there is often not a direct path available between the movement starting and ending points, due to obstacles in the path that may occur from already assembled parts of an object and, because of the lack of a direct path, the times for the movement may be extended due to the lengthening of the movement path. There is very little data available that quantified the additional times that may be necessary to perform such movements, apart from several statements in predetermined motion time systems (PMTS). PMTSs are commonly used for estimating work times, where the engineer can by means of a set of tabulations for different forms of movement and for different amplitudes and final accuracy required, add up component times to obtain a reasonably accurate estimate of the time required by the worker (usually such that 85% can maintain that speed of working). These systems have been used for decades by engineers and have been challenged for their assumptions such as additivity of times for components, differences between systems and accuracy of the predicted times (for example Genaidy et al., 1989). It is in this context that the experiments reported here were carried out: no PMTS gives a clear way to estimate the effect of path angle changes or the circumstances under which time allowances for the change of path angle are required to be made.

For example, in Basic Motion Times (Bailey and Presgrave, 1958), it is stated that when the path is curved, the total path length takes into account the effect of path angle change, whereas if there is a sharp change of path angle, it is necessary to consider the two portions of the movement as separate and times are based on the amplitudes of the two parts. The problem is treated differently in the Work Factor PMTS (Quick et al., 1962) where it is the path deviation from a straight line that is used to define whether there is an effect of the path angle change. This is done in four ranges: where the deviation is less than one-third the amplitude of the movement, no extra time need be allowed; when the deviation is between one-third and equal to the movement amplitude, the time is taken as the time for the sum of the two segments. In the most extreme case of deviations greater than three times the movement amplitude, the two movement segments are treated as separate movements. Both of these PMTSs indicate that there is a critical angle change above which the motion must be treated as two separate components and that additional time must be allocated for calculating movement time. However, neither of these PMTSs give any data to support the effect of angle change. Other PMTSs, such as MTM (Maynard et al., 1948) and DMT (Geppinger, 1955) make no direct mention of the effect of changes in movement direction.

1.1. Forms of movement

There are basically two forms of arm movement that are used by humans, depending on the situation and, in particular, the accuracy required at the end of the movement. Ballistic movements are ones in which the movement, once started is carried out to completion, without any control during the movement in order to make corrections to the path or the end point. On the other hand, visually-controlled movements have ongoing control during the course of the movement (usually visual) and corrections are made to the path when the person sees that the movement is not going to be completed with the required accuracy. Mathematical models for ballistic and visually-controlled movement times have been developed in order to address the assumptions about elemental independence and additivity that are made in PMTSs. These mathematical models were originally developed by Fitts (1954) and Fitts and Peterson (1964) for visually controlled movements and Hoffmann (1981) and Gan and Hoffmann (1988a,b) for ballistic movements in relating movement time with variables such as amplitudes and target widths.

For single-component visually-controlled movements the movement time (MT) is well described by Fitts' law (Fitts, 1954; Fitts and Peterson, 1964),

$$MT = a + b\,ID \quad \text{where} \quad ID = \log_2(2A/W) \tag{1}$$

and for ballistic movements, the MT is given by (Hoffmann, 1981; Gan and Hoffmann, 1988a)

$$MT = a + b\sqrt{A} \tag{2}$$

where A = amplitude of the movement, W is the target width and ID is Fitts' index of difficulty.

When movements have more than a single component, it is found that interactions may occur between components of the