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Leg/foot movement times with lateral constraints

Alan H.S. Chan*, Errol R. Hoffmann, K.M. Ip, Samuel C.H. Siu

Department of Systems Engineering and Engineering Management, City University of Hong Kong, Kowloon Tong, Hong Kong

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ABSTRACT

Much is known about leg/foot movement times when there is a single target constraint - that in the direction of the movement. We report two experiments that investigated the effects of an additional constraint that was perpendicular to the direction of the movement. In Experiment 1, a standard Fitts' task was used but with targets that varied in height and, in Experiment 2, we used the Drury tracking task of moving between lines of varying track widths. Results were different to those of arm/hand movements. In experiment 1 the effects of the Indexes of Difficulty (ID) in the direction of, and perpendicular to, the movement direction, were linearly additive. This is compared to the 'greater ID model' that gives a good description of arm movements. When tracking between parallel lines, foot performance is poor compared to arm performance when error rates are controlled. The Drury model well describes data for arm and foot movements, when the error rates are controlled, but initial error rates increase rapidly with decrease of target width and hence the leg/foot system has difficulty in control at higher values of amplitude to track width ratio.

Relevance to industry: The foot is commonly used for controlling a device. This research demonstrates the effect of having limited width of a target perpendicular to the direction of movement of the foot/leg. Performance is compared to that of the hand/arm system.

1. Introduction

Generally, foot controls are not employed as widely as hand controls for industrial applications and elsewhere. When foot controls are used for control, as for example in automobiles, aircraft and sewing machines, the motivation is to release the hands for control activities that require more attention, like steering or guiding. In general, if we can arrange to assign some controls to the feet, the very great advantage is that the hands are then free to perform other more demanding tasks requiring higher precision and dexterity (Kim and Kaber, 2009; Wagner et al., 2009). For example at computer workstations, data entry tasks invariably require the use of the two hands for text input and cursor positioning. The design and physical arrangement of keyboard and mouse do not allow these two activities to be performed simultaneously. Efficient use of a keyboard requires the continual use of both hands. By clever use of foot controls with appropriate software it may be possible to resolve this dilemma and greatly improve performance. Employing foot-operated input devices would not only reduce the time spent on repetitive keyboard to mouse hand movements, but also provide an additional type of data entry device and also eliminate stress at the wrists, elbows, and shoulders (Springer and Siebes, 1996).

Foot control mechanisms are usually used to control one or a couple of functions, for example in the form of foot-mice for computers, or, brake, and accelerator pedals for cars. Kroemer (1971) measured the speed and accuracy of discrete foot motions for twelve different foot positions, and found that, after a short learning period, people could perform a task with their feet with considerable accuracy. This result indicates that feet may be used for more varied control functions than is currently the case.

Much is known about the effect of movement amplitude and target size when moving to a target at the end of the movement; this is the case for both arm and foot movements. There has been considerable research on foot movements reported in recent times, both for ballistic and visually-controlled movements (see Chan and Hoffmann, 2015), however the only path constraint that has been considered has been on the final accuracy of the movement in the direction of the movement. There has been no study of the effect of constraint perpendicular to the direction of motion on the accuracy and time of the movement perpendicular to the direction of motion. Lateral constraint can occur in two main cases:

(a) Targets of limited height. Participants must aim at a target that not only provides constraint on where the movement is to end in the direction of movement, but also constraint provided by the target perpendicular to the direction of movement.
(b) Tracking tasks, where the participant has to move within

* Corresponding author.
E-mail address: alan.chan@cityu.edu.hk (A.H.S. Chan).

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constraining boundaries for an amplitude A, with a track width of W. For arm movements, a review of various models and data bases is given by Hoffmann (2009).

1.1. Models for movement times

1.1.1. Fitts' tasks

In much research on foot movement times (MT), Fitts' law has been used to quantify the effects of task difficulty in terms of the amplitude of the movement (A) and the final required accuracy in the direction of movement (W). Fitts (1954) law is given by

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

Some research has been reported on the effects of having targets of limited height, so that the movement has to be completed with accuracy both in the direction of movement and also in a direction perpendicular to the direction of movement (Crossman, 1956; Hoffmann et al., 2011). All of this research has been for arm/hand movements. Several different models have been proposed in order to correlate data when there is required accuracy in two or three dimensions (see Hoffmann et al., 2011). The first of these is the original Crossman (1956) model in which the effects are linearly additive so that,

$$MT = a + b\, IDH + c\, IDV \tag{2}$$

where IDH is the Fitts' ID in the direction of the movement, based on the target width W, and IDV is that based on the height of the target (V) perpendicular to the direction of movement.

A further model proposed by Mackenzie and Buxton (1992) is that the movement time is determined by the greater of the two ID values. This model has received some experimental support for arm movements.

$$MT = a + b \log_2[2A/\min(W, V)] \tag{3}$$

Consistent with the model of equation (3), data of Hoffmann and Sheikh (1994) for arm movements showed little effect of target height when it is greater than the target width; in fact, data showed that it is only when the value of Fitts' ID calculated on the target height is greater than about five that there is an effect. Hoffmann and Sheikh identified three regions of control:

(i) At large target heights, only the ID in the direction of motion greatly affects the movement time
(ii) A transition region
(iii) A region where, for small target heights, the movement time is largely determined by the ID based on that perpendicular to the direction of movement.

1.1.2. Tracking (Drury) tasks

A second form of movements in which there is lateral constraint on the movement is that of tracking, where the probe moved by the participant has to be moved through a track defined by a set of parallel lines. For the tracking tasks, the relationship between movement time (MT) and track length (A) and track width (W) is

$$MT = a + b\,(A/W) \tag{4}$$

The model that describes data for this task is that of Drury (1971); the large amount of experiments on this task have been reviewed by Hoffmann (2009), where it is shown to give an excellent fit to data for arm movements as well as for such diverse tasks as sewing, driving a tractor through a gap and moving hospital trolleys. Again, there is no reported data for the times or accuracy with which leg/foot movements may be made in such a tracking task.

Thus the aim of this research was to investigate the capability of the leg/foot system to make movements with lateral constraints, using the two forms of movement task described above. We are assuming that all movements are made with ongoing visual control rather than ballistically, where the movements are pre-planned and carried out without modification. Past studies indicated that the conditions for the movements to be made under visual control with arm/hand movements are with ID > 3 for Fitts' task (Gan and Hoffmann, 1988) and with a (A/W) > 10 for the Drury tracking task (Thibbotuwawa et al., 2012; Senanayake et al., 2015).

2. Method

2.1. Experiment 1: Fitts' task with targets of varying height

2.1.1. Participants

Forty students from City University (21 male and 19 female), Hong Kong aged between 19 and 24, with a mean of 21.0 took part in the experiment. They used their right foot in making movements as described in the following. All were fully informed of the purpose of the experiment and took part under the ethical guidelines of City University of Hong Kong. No participant had self-reported physical or visual problems that might have affected the outcome of the experiment.

2.1.2. Apparatus

A set of target boards were constructed onto which were copper targets of the designed width and height. These targets were connected to an electronic timer measuring to an accuracy of 1 ms. The timer started when a probe attached to the shoe of the participant left a home plate and stopped when the target was hit. The participants were seated on an adjustable chair so that they were able to have a clear view of a probe attached to the front of the shoe and projecting a distance of 40 mm from the front of the shoe.

2.1.3. Experimental conditions

The task was a Fitts' aiming task, but with targets that are of limited height perpendicular to the direction of movement. At each of the target widths in the direction of movement, there was a set of target widths perpendicular to the movement.

There were 27 experimental conditions in which amplitudes of movement 200, 400 and 600 mm, IDH values were 4, 5, 6 and target heights perpendicular to the direction of movement were 20, 10 and 5 mm. These target heights, combined with each of the amplitudes gave IDV values of 4.32, 5.32, 5.91, 6.32, 6.91, 7.32 and 7.91 (several of these values were duplicated by the design of amplitude and target height). Tasks were to move either in the sagittal or lateral directions. The order of direction was balanced across participants and the 27 conditions within each direction were made in a different random order by each participant (See Fig. 1a and b).

A sharp pointed probe was attached to the front of the shoe and projected a distance of 40 mm in front of the shoe so that the participant had clear vision of the movement. Participants were seated so that they were able to see the pen attached to their shoe and were able to guide the pen throughout the task. The dependent variable was the movement time from leaving the home plate to hitting the target.

2.1.4. Procedure

The participant was comfortably seated and adjusted posture to have a clear view of the foot-attached probe. Movements were made in either the sagittal or lateral directions to the targets that were placed on the floor. The order of direction of movement was balanced across participants. Practice was given at each condition until the participant felt confident of the task and, if an error occurred (such as missing the target) that trial was repeated at the end of the sequence of experiments.

2.2. Experiment 2: foot/leg moves in a tracking task

2.2.1. Participants

A different set of 42 participants (21 male and 21 female) took part

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