TIME DELAY AND TASK FACTOR EFFECTS ON AIMED MOVEMENT PERFORMANCE IN A 3D VIRTUAL ENVIRONMENT

Robert G. Eggleston
Research Psychologist
Armstrong Laboratory (USAF)

&

William P. Janson
Human Factors Engineer

&

Kenneth A. Aldrich
Senior Systems Analyst
Logicon Technical Services, Inc.

Abstract

Four experiments assessed aimed movement performance in a 3D Virtual Environment (VE). In general, movement times were found to be described by Fitts’ Law, and thus are similar to movements made in a real physical environment. Movement performance in the VE, however, was degraded by around 28% relative to a comparable physical situation. Virtual Reality system time delay (83 msec over base delay) further disrupted aimed movement performance by about 60% for task difficulties at a moderate level. Little loss in performance occurred under low and high difficulty conditions due to system transport delay. Experiment III extended the aimed movement task to include terminal force control, as well as position control. The effect of this added constraint on movement performance was proportional to the magnitude of the new constraint. This experiment extends the applicability of Fitts’ Law to a wider class of task variations. The data suggest force control is an additive factor to the Index of Difficulty term in the standard Fitts equation.

Introduction

Designers make many decisions in the course of system development. For example, they have to determine things like 1) whether or not to include stereoscopic visual presentation, sound localization, or haptic capabilities; 2) what level of fidelity to include in behavioral models; and 3) how to manage system time delays. In short, designers must make many decisions that have cost, schedule, and human performance implications. As part of the decision making process, it is important for designers of virtual reality (VR) systems to have a thorough understanding of how properties of the system interact with human processes to impact task performance in an interactive virtual environment. Decisions about hardware, software, environmental and behavioral models determine how a virtual environment (VE) looks and behaves which, in turn, influences human performance in the environment.

Tools are needed to help VR developers systematically and quantitatively relate properties of VR technologies and system architectures to human performance. The type of data required may be called psychophysical, since it associates behavior variables with physical ones. Classic psychophysical variables relate a physical variable in the natural world with human sensing of that variable. The Sone scale, for example, relates sound pressure level with the perception of loudness. In like manner, system-based psychophysical variables for a VR development effort would relate properties of the physical system to one or more aspects of human cognition, perception, and/or motor performance.

Psychophysical variables provide a quantitative measure of the relation between user and VE properties. By combining two or more sets of these variables, performance nomographs may be formed. In effect, each nomograph defines a design trade-off space that can be used to set human performance based requirements in terms of system properties (Eggleston, 1994, 1995). Further, the design trade-off space can also help the designer to envision alternative design paths that can be taken to satisfy an established requirement. One aim of our group is to produce a set of design trade-off nomographs for interactive, multi-modal VR systems.

The experiments reported here were undertaken as a step in the process of acquiring the type of data needed to produce design trade-off nomographs to support VR system design. The basic aim of this study was twofold: 1) to determine the relation of aimed arm movement performance in a VE relative to natural environment conditions, and 2) to determine how general aimed movements are affected by time delay in a VR system.

Background

Aimed movements refer to the general class of tasks that require a person to reach out and make contact with an object or spatial point located some fixed distance away from the actor. The majority of research on this topic has

Presented at the 1996 IMAGE Conference
attempted to determine how accurately and rapidly a person can contact objects of different sizes. Typically, object locations are limited to the forward hemisphere surrounding the actor, but there are exceptions (e.g., Warrick, Kibler & Topmiller, 1965). Aimed movements are a component of many types of tasks, including activating switches, reaching and grasping a control, pointing to objects, and selecting an item with a mouse or wand. Knowledge about aimed movement performance, therefore, has wide applicability to many types of tasks that can be performed in a VE.

Aimed movement behavior has been studied in human performance laboratories at least since the time of Woodworth, whose classical work on the topic continues to be cited (Woodworth, 1899). A consistent interpretation of this body of knowledge was not forthcoming, however, until the 1950’s when Paul Fitts proposed that aimed movements were governed by a speed-accuracy trade-off. Fitts, motivated by concepts from information theory, devised a measure to quantitatively capture the proposed trade-off. The measure, called the Index of Difficulty (ID), asserts that movement time (MT) is directly proportional to the distance to the target, and inversely proportional to the width of the target object. In a classic series of papers, Fitts showed that aimed movement time was linearly related to the Index of Difficulty, thereby confirming the efficacy of the speed-accuracy concept (Fitts, 1954; Fitts and Peterson, 1964).

In the spirit of information theory, the mathematical relation describing the speed-accuracy trade-off is typically expressed in log₂ form: MT = a + b (Log₂ 2A/W), where A is the amplitude or distance between a start position to the target (or between two targets that alternate as the start point), ID is the Index of Difficulty, and a and b are constants related to the limb segment involved in the movement and other context factors. Numerous studies using, for example, arm, head, and foot movements, have shown that this speed-accuracy relation accounts for the data to a remarkable extent (e.g., Langolf, Chaffin, and Foulke, 1976; Drury, 1975). This relation, now known as Fitts’ Law, in honor of its creator, is among the most robust findings in human performance science.

Aimed movements may be used in virtual environments to operate buttons and switches on virtual equipment interfaces, to directly reach out and touch or grasp objects or locations of interest in 3D volumetric space (without hitting intervening objects), or to position and reposition tools used in any task ranging from surgical rehearsal and training to maintenance repair and manipulation of dense data sets (e.g., scientific visualization). Since aimed movement enters into such a wide range of application tasks, it would seem to be an ideal candidate to use as a tool to compare motor performance in a VE with that obtained in the natural environment. Indeed, since Fitts’ Law establishes a quantitative psychophysical relation between aimed movement and spatial properties of a VE, its value as a design tool is further enhanced.

Four experiments dealing with aimed movement in a 3D virtual environment are reported in this article. All of them required the actor to move a virtual stylus reciprocally between two targets as task difficulty level was varied. Since this task has been widely reported in the literature, its use here facilitates comparison between the assessment of human performance in a VE with similar performance in a natural environment. Further, by making contact with the extent data base in this way, fewer new experiments may be required to acquire data applicable to a wide range of VE task situations.

Experiment I is a direct replication of a reciprocal tapping study performed by MacLeod and Martin (1978), with the exception that it is performed in a VE. It shows that, in general, Fitts' Law holds over a range of ID levels in VE conditions. However, one possible exception is noted. Experiment II attempts to determine how much of the performance reduction found in the VE is, in fact, due to the VE, as opposed to other factors such as VE experience of the actor and possible differences in task conditions from the MacLeod and Martin study. The results produced the same general trend as Experiment I, but with improved performance in the VE conditions. Experiment III is an attempt to extend the tapping task paradigm to cover tasks with more severe spatial constraints. Hence, the results would apply to a wider range of application situations. The results illustrate the added cost associated with controlling force of movement as well as control of movement terminal location. Further, they demonstrate that task difficulty follows the same basic Fitts’ Law structure under these more demanding conditions. This experiment provides a novel and original extension to the understanding of aimed movement performance. Experiment IV provides a preliminary assessment of how time delay in a VR system impacts aimed movement. The results show a substantial movement time cost when task difficulty is in the mid ID range, but little cost when tasks are either very easy or extremely hard.

Experiment I

The goal of this experiment was to determine if aimed movement (AM) performance in a VE is comparable to AM performance under similar physical conditions. As a secondary issue the effect of different types of performance feedback was also assessed. The main reason for this manipulation was to determine if cognitive demand or the use of multiple sensory channels has any added effect on aimed movement times.

The logic behind the experiment is straightforward. If AM performance in the VE is the same over the tested levels of difficulty as that found in the natural environment,
then it is reasonable to conclude that real-world performance can be achieved in a VE. If it is found that Fitts’ Law holds but the slope of the function is different, then it implies that the relative magnitude of work in the VE will differ from that in the natural environment. It also implies that the VE does not induce the actor to make any change in strategy or coordination to accomplish the task. Thus, it follows that there should be a strong positive transfer of psychomotor skill acquired in the VE to its use in a comparable situation in the real-world task. This reasoning applies to all four experiments.

**Experimental Design**

A 6 by 4 completely within subjects factorial design was employed. The factors consisted of Index of Difficulty level (ID = 2,3,4,5,6,7), and Performance Feedback (four types: Visual-Augmented, Auditory, Symbolic, and Visual-Intrinsic). A Latin Square procedure was used to counterbalance presentation order within a feedback condition. Twelve target width/amplitude (i.e. movement distance) configurations were presented in random order. The configurations covered the range of ID levels, with some IDs reflected in multiple configurations. The number of configurations per ID were as follows: one each for IDs 2 and 7, two each for IDs 3 and 6, and three each for IDs 4 and 5. (This procedure of acquiring unequal data by ID level is a common practice in the human performance literature.)

**Apparatus**

The study was conducted in the Virtual Environment Interface Laboratory (VEIL) located in Armstrong Laboratory at Wright-Patterson AFB, Ohio.

**VR system.** A 3D visual virtual environment was produced by a VR system composed of an Ascension Bird magnetic tracker, a 486 PC with an IRISVISION graphics card, and a SIM EYE head-mounted display (HMD) system by Kaiser Electro-Optics. The SIM EYE was configured to provide two 40-degree circular field-of-view oculars which were collimated to optical infinity and provided completely overlapped imagery from a single source.

The virtual environment consisted of a table in a monochrome rendition of a rectangular room depicted in perspective from the subject’s eye position. The environment was “head stabilized,” meaning that it did not move with head movements. Two 2-dimensional shapes (rectangles) were coplanar with the table in front of the subject. Using a left-hand coordinate system, the targets were placed an equal distance from the mid-line of the subject along the X-axis approximately 23 inches (mid-line of the targets) in front of the subject. A square shaped “home” position at the intersection of the subject and target mid-lines was also shown, along with a stimulus light. The basic arrangement, including the virtual stylus used to touch the targets, is shown in Fig. 1. Target depth (Z-axis) was held constant at 2.75 inches across all conditions. Target width varied from 0.25 inches to 2.0 inches and target separation (center to center) ranged from +/- 2 to +/- 8 inches about the home position mid-line, depending on ID condition.

**Subjects and procedure.** Eight males recruited from a local university served as subjects. All subjects were paid for participation and passed an eye examination. The task consisted of moving the stylus back and forth between two static targets, touching each target, in turn, 15 times for a total of 30 taps per trial. Tapping was performed without aid of arm support. Subjects were instructed to tap the targets as fast and as accurately as possible. All trials started with the stylus at the home position. Once the stylus was maintained in the home position from 1 to 2 1/2 seconds, the stylus light was turned on. Four practice trials were provided prior to data collection. A 5-minute rest break was provided after half of the 48 experimental trials were completed.

**Performance feedback.** The VE provided all subjects with visual feedback concerning the accuracy of their performance. We refer to this naturally occurring feedback as the Visual-Intrinsic feedback condition. In a second condition, the entire target illuminated when it was touched by the stylus. This was called the Visual-Augmented condition. In a third condition, an audio tone, provided through the SIM EYE headset, came on when a target was touched. This was called the Auditory feedback condition. The final condition provided a + or - sign immediately below the target being tapped. Thus, this feedback required
at least a weak form of cognitive processing. This was called the Symbolic feedback condition.

Results and Discussion

Data was collected from a total of 11520 taps. Target hits were made 93% of the time. The fact that some errors were made indicates subjects were motivated by both speed and accuracy factors. MacKenzie and Buxton (1992) have argued on theoretical grounds that an error rate around 4% is ideal. Thus, the error rates were a bit higher than desired, but in the typical range found in the literature. Following standard practice, the detailed analysis was confined to the correct hit data only.

Mean movement times, by Performance Feedback condition, collapsed over the ID variable, were: Visual-Intrinsic- 941 msec., Visual-Augmented- 882, Auditory-920, and Symbolic- 904. These differences were not statistically significant according to an ANOVA (F (3,21) = 0.57, p =.641).

Fig. 2 shows group mean movement time (MT) as a function of Index of Difficulty. A regression line, based on data from MacLeod and Martin (1978), is also shown in the figure for comparison. It is clear that the data for IDs 2 to 6 are well described by a linear function. This confirms the Fitts' Law characteristic over the ID 2 - 6 range. Movement times are slower in the VE condition compared to the MacLeod and Martin study, and the rate of change in difficulty is greater. The inverse of the slope of the regression line is often used as an Index of Performance (IP), expressed in bits/sec. IP provides a convenient measure to compare the performance between the task in the VE with that in the normal physical environment. IP for the MacLeod and Martin experiment is 11.8 bits/sec. IP for the present experiment is 4.9 bits/sec. Based on this index, aimed movement performance was degraded by 68% relative to the real-world analogue. Thus, while subjects behaved in a manner that was essentially consistent with Fitts' Law, apparently the task in general was more difficult in the VE.

The data for the ID 7 condition suggests that a nonlinear effect in task performance begins to show up somewhere between an ID 6 and ID 7 level (See Fig. 2). We suspect this departure from Fitts' Law is based on a combination of factors found in the VE. An investigation of this effect is in progress.

Experiment II

The tapping task is very easy to learn and, therefore, little training or practice time is needed. However, we noted that most of the subjects appeared a little uneasy about wearing a helmet-mounted display (HMD) system for the first time. This was a novel experience for students in 1994 when this experiment was performed. In addition, a further review of the MacLeod and Martin study raised questions about comparability of conditions with our experiment. Specifically, it was not clear whether or not their subjects performed the task in a standing or sitting position. If their subjects were standing and ours were seated, this would have a large impact on movement times. Given these concerns about the subjects and comparison case from the literature, a slightly modified version of the experiment was constructed and performed by four subjects with considerable experience using HMD systems.

This experiment again compared reciprocal tapping performance between a real-world physical case and the virtual environment case. The physical environment was an exact replica of the VE, and subjects were seated at the same workstation in each situation. Nearly identical stylus were also used across conditions. Only the Visual-Intrinsic feedback condition was employed, and taps per trial were reduced from 30 to 20. The 12 width/amplitude configurations, over the same 6 ID levels used in Experiment I were tested.

Results and Discussion

A total of 2880 taps were collected across four subjects. Combined error rate was 2.4%. Group mean movement times are shown by ID level in Fig. 3. Data from the physical condition (open squares) are quite similar to the regression line taken from MacLeod and Martin (1978). Movement times are slower for IDs 5, 6, and 7, which causes the slope of the curve to be steeper (see Fig. 3). This indicates that at least some of the loss in performance under the VE condition in Experiment I was due to our task situation and not due to the VE, per se. All future comparisons with a real-world condition will be based on the new data from this experiment.

Data for the VE condition were collected at a separate time. As in Experiment I, movement times (open circles) appear to be approximately linear for IDs up to 6. Between ID 6 and ID 7 the same nonlinearity is evident in the data (See Fig. 3). A regression analysis produced $r^2$ values of
.951 for the physical condition and .987 for the VE conditions (excluding ID 7 data). The Index of Performance was 7.43 and 5.4 for the physical condition and VE conditions, respectively. Based on the ratio of these IPs, performance was reduced by about 28% under the VE condition.

Experiment III

Many developers and potential users are excited about the prospect of developing VEs that can be used for medical training, including developing and rehearsing new or modified procedures. Designers of VR systems must determine what aspects of medical education can be satisfied with, say, a visual-only VR system and when sound, localized sound, or haptic feel capabilities are needed. Human performance data is essential to these decisions. Imagine a surgeon trying out a new procedure in a visual-only VE. It occurred to us that in such an application, it would be important for the surgeon to control the force of movement of the scalpel on simulated tissue, as well as position the scalpel at the right place in a reasonable amount of time. We abstracted and generalized this thought to produce a more highly constrained tapping task. In this task, the actor must not only move back and forth between two targets, but also control the depth of penetration down into the targets when tapping them. The targets in this task, therefore, become rectangular columns or buttons that can only be depressed so far without damage. We use the term Penetration Limit to define the acceptable limit of depression.

MacKenzie correctly points out that the original formulation of Fitts' Law only applies strictly to a one-dimensional task. Even though two-dimensional plane objects are used in the task, in a classic setup the length dimension is deliberately made large enough to reduce its effective ID level to below 2. This means principle movement control is largely limited to one direction. MacKenzie (1992) has investigated different ways to extend Fitts’ ID formula when both X and Z (left-hand coordinate system, Y up) object dimensions come into play. The new task to be investigated in this experiment also imposes constraints on the actor in two dimensions. However, MacKenzie’s extension does not apply to this task, since the added Y axis spatial constraint on the target acts as a force constraint on performance rather than an additional location constraint. In effect, the new task is a two-dimensional one with a 3D target in a 3D environment. MacKenzie’s work applies to 2D targets in a 2D or 3D environment. The purpose of this experiment was to determine how movement time is affected when task difficulty is changed by manipulating both force and location constraints on motor control.

The VE was essentially the same as before, except that targets were 3D columns, as shown in Fig. 4. A line that defined a plane through each column was visible around the outside edge of each target. This defined the Penetration Limit. If, after touching a column, the stylus tip position was lowered into the target, the top of the column would depress, like a panel-mounted switch. If the tip penetrated below the limit line, the column would implode. This clearly identified an error.

Experimental Design

A 5 by 4 completely within subjects factorial design was employed. The two factors were ID Level (ID = 2,3,4,5,6) and Penetration Limit (Pp) (0.25, 0.30, 0.75, and 1.50 inches). Three different configurations were used for each ID level. Configuration and Penetration Limit pairs were presented in random order for each subject. The same four subjects from Experiment II participated in this experiment. As before, trials consisted of 20 taps each.
Results and Discussion

The total data set consisted of 6000 taps. Errors accounted for 5% of the data. Following usual practice, the analysis was confined to the correct hit data only.

Group mean movement times are shown in Fig. 5 as a function of ID calculated according to the Fitts formula. Penetration Limit is the parameter. It is clear from visual inspection that performance is approximately linear for each level of penetration tolerance. Further, as expected, movement times are inversely related to Penetration Limit. An ANOVA confirms a main effect for both ID (F(4,12) = 49.20, p < 0.0001) and Penetration Limit (F(3, 9) = 53.21, p < 0.0001). No significant interaction was found.

These results may be interpreted to mean that the added constraint on movement control required by the 2D task, in effect, increased task difficulty. As a design tool, it would be desirable if the increased movement time resulting from added task difficulty, due to the force constraint, could be defined as a correction factor added to MT as calculated in the standard manner. The obvious benefit would be that MT estimates under standard 1D tasks could easily be extended analytically to the more complex task situation involving a mixture of force and location constraints.

The data shown in Fig. 5 appear to be well behaved and suggest Penetration Limit could be an additive component to task difficulty. Fig. 6 portrays the same data in terms of change in movement time ($\Delta MT$) as a function of Penetration Limit. The relation appears to be linear. This again suggests that the Penetration Limit constraint can be regarded as an added component to task difficulty.

$\Delta MT$ was derived by relaxing the penetration limit constraint. In this experiment Penetration Limit level 1.50 was the total height of the column. Therefore, the penetration limit may be regarded as completely relaxed in this condition. In effect, the difficulty of the task collapses to the classic 1D case, and Fitts' ID formula applies. $\Delta MT$ is easily formed by subtracting the movement time associated with the 1.50 Penetration Limit condition from the movement times found in the Penetration Limit conditions.

Based on the assumption that there is a linear relation between $\Delta MT$ and penetration limit, it is easy to derive a general expression that can be used to calculate a correction to Fitts' Law: Let $P_{\text{max}}$ be the maximum length of an object in one dimension (here it is height). The variable $P$ is defined as penetration limit ($P_{L}$)/$P_{\text{max}}$, which is nothing more than expressing $P_{L}$ as a proportion. Since by assertion

$$\Delta MT = a + b P_{L},$$

(Eq. 1)

it follows by substitution that

$$\Delta MT = a + b P(P_{\text{max}}).$$

(Eq. 2)

Now, when a penetration limit is added to an aimed movement task, movement time can be estimated by adding the $\Delta MT$ value to MT as calculated in the normal manner with the Fitts equation.

For the conditions used in this experiment, the slope and intercept for Eq. (2) are estimated to be -1351.629 and 1121.040, respectively. These values are likely to be higher than when the same type and magnitude of penetration constraints are encountered in the physical environment, given the findings under VE conditions reported earlier.

For theoretical reasons, we have also developed several new models as alternative ways to express ID when a penetration constraint is present in the task. Many of these models are in the same spirit initiated by MacKenzie. The results of this model development work is forthcoming (Eggleston et al., in preparation).
Experiment IV

The final experiment considers the impact of time delay in VR systems on aimed movement performance. A fully synchronized VR system was used. System time delay was manipulated in two different ways. Type I time delay addresses the case where tracker data is held for additional frames before affecting the display image. A high display update rate is maintained (e.g., 60 Hz). Type II time delay addresses the case where the display update rate is decreased. Each display update reflects current tracker data. These two forms of delay have different perceptual consequences. Type I time delay produces a "pure event lag". Movements are perceived to be smooth, but lag behind stylus position. A rubber band effect occurs with changes in velocity. Type II time delay produces lower lag intervals and longer image dwell times. In general, movements are perceived to be jerky, with multiple ghost images, depending on velocity and other factors. In this experiment, five levels of Type I and Type II delays were introduced into the VR system by inserting hold buffers after the tracker stage or display stage, respectively. Delays were in increments of the display update rate of 60 Hz. A total of five added delay steps were investigated for each delay type. The standard tapping task was executed over 6 ID levels (ID = 2,3,4,5,6,7). Data was collected from three experienced subjects.

Results and Discussion

The results based on mean data are portrayed graphically in Fig. 7. It can be seen that for most delay conditions the effect, in general, was fairly small. The linear relation between MT and ID is still evident. Interestingly, the nonlinearity previously noted for ID 7 does not appear in these data.

Only two conditions stand out in this data set. Both are for a VR system with end-to-end time delay of 142 msec. One is a Type I form of delay while the other is a Type II. These two conditions can be seen more clearly in Fig. 3. From Fig. 3, it is clear that time delay has some effect on movement times over the ID 4 - 6 interval, with the largest effect occurring at ID 5. In relation to the baseline VR system (open circles in Fig. 3), which had a 58 msec delay, the addition of 83 msec delay served to increase movement times by about 60%. Even though the results are preliminary, they seem reasonable and can be easily interpreted.

Little or no time delay effect at the extreme ID levels follows logically from two facts. With low IDs, the actor does not depend on visual feedback to perform the task. As a result, the actor operates in an open loop fashion and ignores any visual input, delayed or otherwise. When task difficulty is very high (e.g., ID 7), even without delay, the actor tends to use a series of micro-movements that appear like a move-hold pattern near the target. If the hold time is equal or greater than the system delay time, this behavior pattern nulls out any time delay effect.

Unfortunately, the sizable adverse effect of time delay at the mid ID level is cause for concern for at least two reasons. It is common for switches, buttons, and other target objects to be designed to produce an ID in the 4 to 5 range. This is a region where aimed movements can be made accurately with minimal active attention required, and target sizes are well scaled to the human hand. Further, the absolute size of the objects tends to be reasonably scaled to the entire scene. Hence, it is often a good design trade-off to select target sizes in this region.

The increased movement time induced by time delay suggests that it adds confusion or disrupts normally fluid movements. This time delay effect warrants closer examination.

General Discussion and Conclusions

The results from three of the four experiments are summarized in Table 1. In general, the r² values for the VE conditions were comparable to the real-world cases shown in the table. Thus, it is clear that the Fitts’ Law approximation holds for aimed movements in a 3D VE.

The Index of Performance ratios shown in the last column of the table expresses performance under VE conditions as a percentage of performance under real-world conditions. It is clear from this index that in absolute terms aimed movement performance was noticeably worse in the VE. The best estimate of relative loss of performance was about 28%. This suggests workload levels will be higher in a VE. But, since the basic linear form between MT and ID was found in every instance, there is good reason to believe
TABLE 1.
Summary of Results: Experiments I, II, and IV

<table>
<thead>
<tr>
<th>EXPERIMENT</th>
<th>ID Range</th>
<th>Regression Coefficients</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
<td>R²</td>
</tr>
<tr>
<td>MacLeod &amp; Martin</td>
<td>2</td>
<td>7</td>
<td>.897</td>
</tr>
<tr>
<td>(physical)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experiment I</td>
<td>2</td>
<td>6</td>
<td>.922</td>
</tr>
<tr>
<td>Experiment II (physical)</td>
<td>2</td>
<td>7</td>
<td>.951</td>
</tr>
<tr>
<td>Experiment II (VE)</td>
<td>2</td>
<td>7</td>
<td>.987</td>
</tr>
<tr>
<td>Experiment IV (VE)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Time Delay Type I</td>
<td>2</td>
<td>7</td>
<td>.912</td>
</tr>
<tr>
<td>b. Time Delay Type II</td>
<td>2</td>
<td>7</td>
<td>.936</td>
</tr>
</tbody>
</table>

¹ Index of Performance Ratio (IP Ratio) is the aimed movement performance under VE condition relative to a physical baseline from Experiment II.

there will be positive transfer of training between VE and real-world task situations.

The psychophysical data presented in Experiment IV that related human movement times to the system property of time delay is an example of the type of data design engineers can use to make user-centered design trade-off decisions. Ideally, the data base would describe aimed movement along dimensions that could easily be mapped into application task situations. This would allow the designer to select a slope and intercept for the Fitts equation that best relates to their situation. Thus, analytical estimates could be made without the need to collect new data.

The extension of aimed movement analysis to cover task situations that require force control as well as location control is a promising development. The data presented here indicates that the added difficulty associated with this new task constraint simply adds to difficulty as defined by Fitts. If difficulty of movement under this and other types of constraints can be accounted for by a simple extension of Fitts’ original formula, then there will be a substantial increase in the range of conditions over which aimed movement data can be applied. Obviously, this would extend the utility of Fitts’ Law as a psychophysically-oriented design tool.

References


