Abstract

Measuring Pointing Times of a Non-visual Haptic Interface

by

Gary Wayne Hrezo

Major Advisor: William D. Shoaff, Ph.D.

An experiment was performed to evaluate the effectiveness of using haptics (force feedback of a manual joystick) in a non-visual computing environment. It was believed that a haptic display would enhance, if not eliminate, the need for the visual sense when attempting to view graphical information. Sight impaired people could use haptic interfaces to facilitate the navigation of human computer interfaces which are, by their nature, graphically intensive. Subjects manipulated a force feedback joystick a random distance until over a vibrating target of random width. An inwards/outwards and right/left test was administrated. Movement times were found to be a linear function of the level of task difficulty as defined by Shannon's formation of Fitts law, $\log_2 (D/W + 1)$. Two linear relationships were found. The first when the joystick traveled the smallest distance and the other with all other distances. Results indicate that haptics could be used to show graphical information.

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1.0 Introduction

1.1 Experimental Motivation

This chapter describes haptics and tools used to measure human haptics throughput.

Navigating the Internet or general computer use is, by nature, graphically intensive. Clearly, this is a problem for sight-impaired people. The purpose of this study was to evaluate the effectiveness of using touch in place of visual graphics while using a computer. It was believed that a touch interface would enhance, if not eliminate the need for the visual sense when viewing graphical information. An experiment was performed using the Fitts (1954) model to evaluate the performance and compare the haptic experiment results to Fitts' results.

Fitts law predicts movement time for many human pointing activates and is consistent with most pointing devices such as a mouse or joystick. Section 1.7 will explain in detail the law and its formation from information theory. For now it suffices to say that Fitts Law predicts the time to move a pointing device a given distance to a target region of a given width (e.g. graphical button). Fitts law is extremely robust (Proctor, 1994) and movement time for any pointing activity may be estimated using Fitts law. Therefore, it is reasonable to suggest that the basic elements of Fitts Law also apply to non-visual pointing.

Haptic interfaces are devices that feedback force to the individual. Instead of visually observing that the cursor is on a "graphical" area, feedback, in the form of force, signals that the individual has moved over the graphical target.

1.2 Haptics Overview

Revesz (1950) first introduced the term "haptics" in 1931, which comes from the Greek "able to lay hold of." Informally, haptics is the ability to sense touch. Without touch simple everyday activities would become extremely difficult. Finding the light switch in a darkened room would require a flashlight; finding keys in a purse would require a visual check of all contents. Even with such everyday importance, touch has not received the research attention that hearing and sight perceptions enjoy (Heller, 1991).

1.3 Haptic Physiological Basics

This section describes the skin's receptors and how they relate to the overall understanding of haptics.

The skin feels touch, pressure, vibration, heat, cold, and pain in varying degrees. These tactile sensations are aroused through mechanicoreceptors, thermoreceptors, and nocireceptors which are the skin's sensors (Salvendy, 1997).

Touch and pressure are sensed by mechanicoreceptors, and those parts of the body that have the highest density of mechanicoreceptors have the most sensitivity. Force was applied on the mechanicoreceptors in this study. Other skin sensors are included for completeness.

Thermoreceptor sensors gather information about temperature for the skin. Pain is detected by nocireceptors.

Revesz (ibid.) coined the term haptics to include both cutaneous (skin stimulation with muscle stimulation) and kinesthetic input (muscle stimulation without skin stimulation, Heller, ibid.). Proprioceptive or kinesthetic sensitivity reveals information about the orientation and movement of joints and muscles. The physical receptors both tactile and kinesthetic work in concert to gather information for the haptic system, which attempts to draw conclusions about a local object or environment.

1.4 Exploring Haptic Environments

Touching, and all aspects of touching (i.e. feeling, temperature, force, shape, hardness), are stimuli to haptic perception. These stimuli are attributes that help characterize an object. Working in conjunction with other senses, touching helps us understand our environment.

Haptics requires action (user input) to explore the environment that, in turn, stimulates perception sensors. We must explore the world; the world does not come to us. For instance, to sense a football we do not quickly touch and release it and then begin thinking football. We grasp it, feel the laces and sense the texture of the pigskin. In this way we built a mental image of a football.

Haptic perception, then, is more than a single sense; it is a discovery system. Touch is an ongoing exploratory process. This system takes input in the form of touching and processes the touch information that leads to more exploratory touching (Gibson, 1962). This exploratory phase of touch can be considered output from the system.

When the only sense available is touch, it is clear that more information about an unseen object will be ascertained by touching the whole form instead of a few sub-parts. Texture, weight, and general shape will emerge to form a "picture" of the unknown object in the mind's eye.

Passive touch occurs whenever exterior objects are pressed against the skin by an outside stimulus and the observer does not explore the object. Information received from a passive touch is vague; however, to fully identify the object, it needs a thorough examination. Gibson (1962) found that identifying objects (without sight) improved from 29% to 74% when subjects held the foreign object and actively felt it as opposed to passively allowing the object only to touch the skin.

Gibson and others (Heller and Schiff, 1991) understood the relationship between *touching* an object and information received passively by the hand (Gibson, ibid.). Gibson wrote:

> Active touch is an exploratory rather than a merely receptive sense. When a person touches something with his fingers he produces the stimulation as it were. More exactly, variations in skin stimulation are caused by variation in his motor activity. What happens at his fingers depends on the movements that he makes-- and also, of course, on the object that he touches. Such movements are not the ordinary kind usually thought of as responses. They do not modify the environment. Presumably they enhance some features of the potential stimulation and reduce others. They are exploratory instead of performatory. In this respect, these touching movements of the fingers are like the movements of the eyes. In fact active touch can be termed tactile scanning, by analogy with ocular scanning.

Haptic exploration, from examination of blind individuals, seems like a haphazard way of moving the hand. Instead of viewing the successive actions of hand exploration as a problem of the blind, recent researchers have theorized about a united perception of form for haptic exploration. Zinchenko and Lomov, for example, developed a theory of haptic perception in which an "image" is made from the movements of the hand (Heller, 1991). They suggested three functions of haptic perception. The first is contour detection, the second deals with finding the extent of the object, and the third uses the hands to develop an "adequate" or an exacting image of the explored object. When hand movements were forced to be continuous by test conductors instead of moving, pausing, and resume moving, subjects failed to identify the object correctly.

Zinchenko and Lomov observed that two repeated actions of the hand are required to comprehend an object: pauses and regressions. Pauses usually occur at corners and intersections on the object. Regressions are repeated movements over previously explored complex sections of the object. Heller reports that only Zinchenko and Lomov have looked into the importance of pauses and regression, and this investigation found little research on the subject although these actions are required in Braille reading. Clearly more research is needed to explain why pausing and starting is important when attempting to identify an object by touch.

Tools, such as canes, can enhance haptic exploration by the hand. The blind use canes to navigate around obstacles. Kennedy (1992) explains how haptic information is realized by cane use. Distance and rigidity information are received when the cane is moved back and forth. Therefore, blind pedestrians must constantly move the cane to continue to receive haptic information and receiving information solely through haptic input slows down the process of walking down a street. The haptic sense, then, is slower than that of sight and the overall "throughput" of the haptic sense is not as effective as visual throughput. This presumption, that haptic throughput is slower than visual throughput, is supported by the experimental results.

1.5 Haptic Perception Research

This section reviews studies of aimed hand movements and the haptic sense. Although haptics is the study of touch, most studies in haptics are concerned with using a haptic interface. These studies are predominately focused on telemanipulation (remote operation a device with haptic feedback) and haptic interface technology and haptic software.

Klatzky and Lederman (1987) discovered that non-sighted subjects found it easy to identify common everyday objects such as a pencil, but these subjects had great difficulty understanding a raised line (relief) drawing of common objects. Objects are much easier to identify and explore when, in Gibsonian terms, the subject can handle and observe. Klatzky and Lederman also pointed out that subjects use a system of moves or *exploratory procedures* that results in better identification (Klatzky, Lederman et al., 1989). An exploratory procedure is a motion pattern that suits the given object perfectly. Lateral motion (rubbing), for example, is useful to detecting texture. Pressure techniques provide knowledge on hardness of the object. Holding an object conveyed weight data and following the whole contour provides shape information.

Gibson's haptic schema seems impossible to describe adequately without Klatzky and Lederman. To understand haptics is to understand that haptic perception is active and the other senses combine (e.g. sight) with touch to produce a total gestalt effect. When picking up objects with both hands to estimate weight, for instance, individuals will feel around the object, poke it for shape and hardness, regardless of whether they are able to look at the object or not.

When conducting experiments, the time the hand moves a given distance define hand movement tasks. Subjects may be required to move from a starting position to a target position, stopping as close as possible to the target, or subjects may merely be required to stop when inside a target zone. Subjects may be asked to move as fast as possible with or without accuracy. Back and forth repeated movements are ideally suited for the laboratory because they are easiest to measure.

For more than a hundred years, aimed hand movement studies have been performed, for example, Woodworth (1899) measured lines that subjects drew in time with a metronome. Woodworth also studied the same task with the subject's eyes closed. Results showed that error increased linearly with mean movement time. More mistakes were made the faster the hand moved, but the errors did not correlate to movement time with eyes closed. Woodworth believed that subjects travel through two phases with aiming their movements: a initial adjustment phase and a current control phase which closes in on the target with precision from visual feedback.

Aimed movements (e.g. with a joystick) are not made in continuous, smooth motion, but are composed of many submovements. Figure 1 shows that initial velocity quickly increases (ballistic phase) and then smaller distances and smaller velocities are required until inside the target region. Current studies found the initial ballistic phase covers most of the distance to the target with error correction phases resulting in closing in on the target with many smaller phases until the target is captured (Crossman and Goodeve 1983).

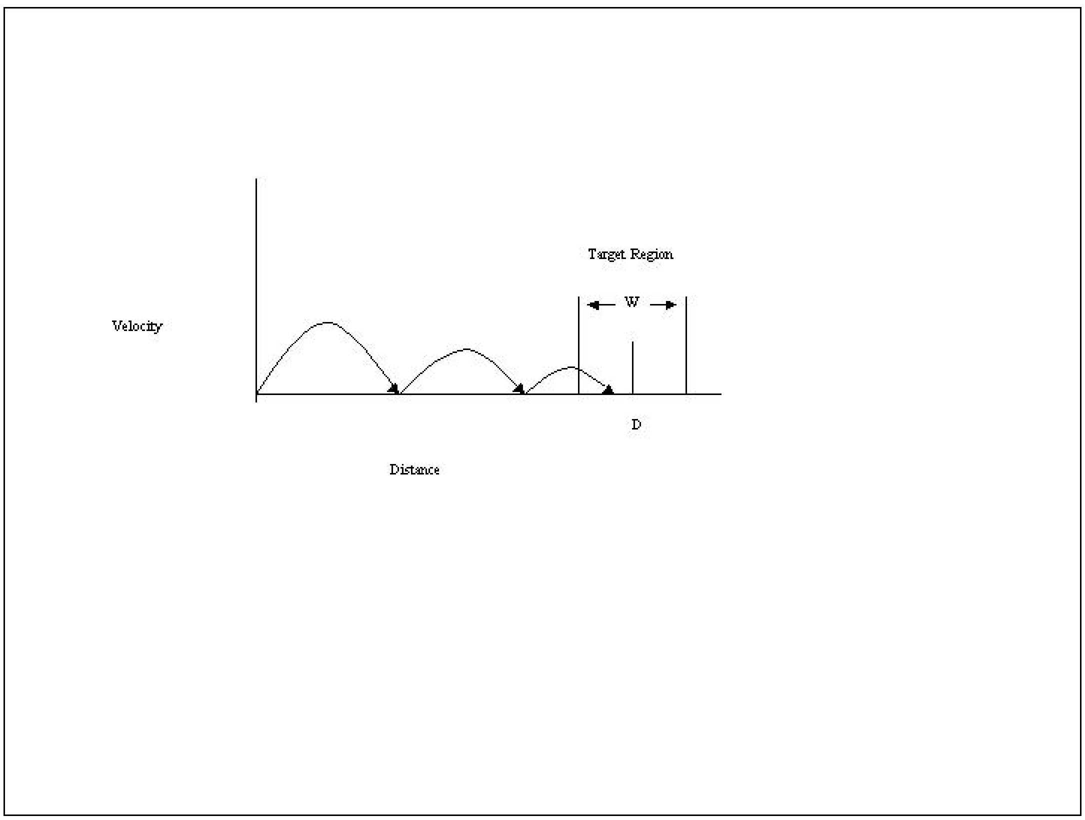

Figure 1. Movement Trajectories with Distinct Submovements

Haptic exploration, also, has distinct submovements. Moving a joystick towards a target is a series of many hand movements. After an original ballistic movement propels the cursor the majority of the distance to the desired target, the remaining distance is a series of corrective movements until the target is finally reached and selected.

1.6 Information Theory

Developed in the 1950s, information theory was a working concept to help explain the propagation of data within a system. Information or data was said to travel between a sender and a receiver linearly. The theory describes the concept of information and the maximum number of messages sent without losing information content (Shannon, 1949). Similar to signals in communication, information is sent though a channel from a source to a receiver. Figure 2 (page 10) shows the components of an information channel.

Not only has information theory been used to model traditional subjects as communications but also the human sensory system has been modeled using information theory. A college professor, for instance, lecturing to students who are listening intently and taking notes is a system that information theory helps model. The encoder places the information into a form for transmission across the system. Let the lecturer depict the encoder and the let student represent the channel between sender and receiver. The notes taken by the student will represent the receiver. Words spoken by the lecturer will travel between the encoder and receiver interrupted by noise. Noise is any disturbance, which causes the data to become perturbed. Someone walking in late being and very noisy would cause a disturbance to the lecture. Encoders attempt to encode the data for better performance (Sanders, 1993). Channel speed between sender and receiver is of interest and was used in the experiment conducted.

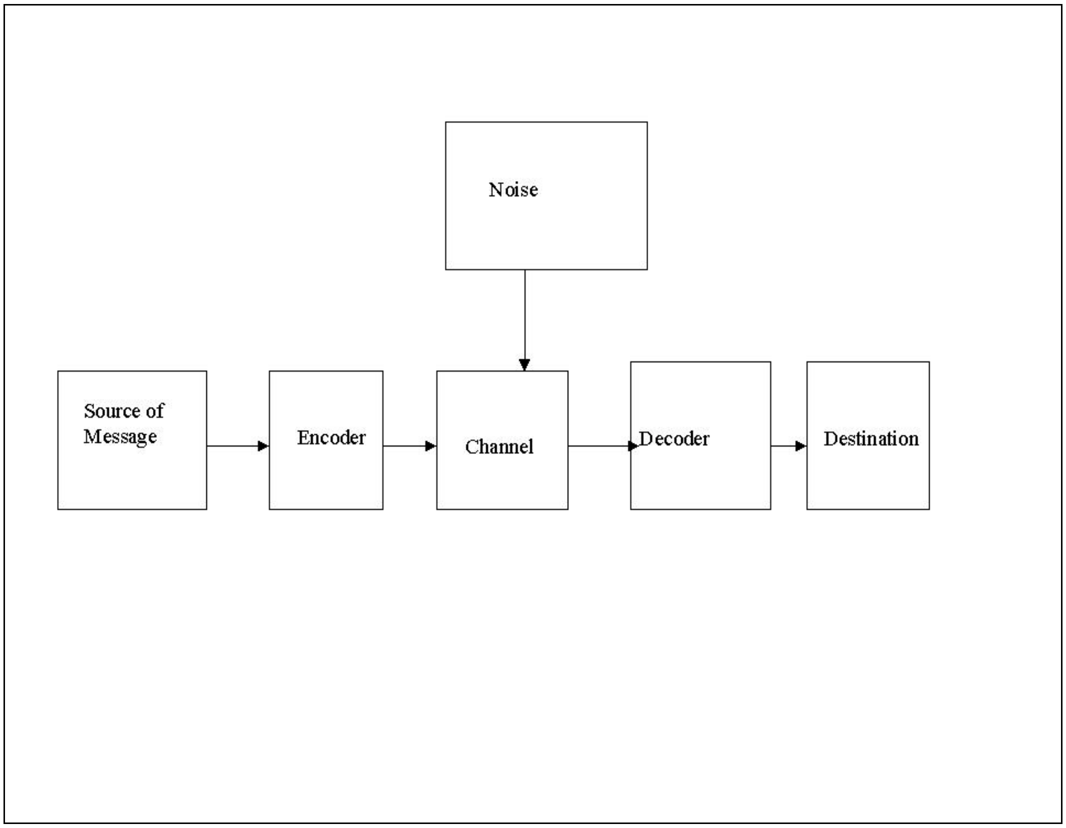

Figure 2. Components of an information channel

Shannon, the originator of information theory, measured information in bits. The amount of information is dependent on the number of possible events or stimuli. Four equally likely events would be expressed as equal to the base 2 logarithm of four ($\log_2 4 = 2$ bits). The information content of a message with four equally likely events would equal two bits. Let H_S equal the number of bits of information from a source. Equation 1, below, shows that H_S express the information available from the stimulus with N equally likely stimuli.

$$H_s = log_2 2\ N\ (1)$$

Many times the stimuli will occur with differing probabilities. Take, for example, someone choosing an integer between one and ten. Assuming the most likely selected number is seven, less information is contained in this pick since seven has a higher chance to be chosen. To compute the information content for some stimulus event "i"

$$H_s = log_2 2 (1/P_{i)} (2)$$

where P_i is the probability of stimulus event i occurring. Every event contains some information. Equation 2 shows the result. A ringing doorbell has informational content. Listening to a speaker can be considered an information system. The speaker is the information source and the listener, the receptor. When the amount of information sent is less than the amount received, information is lost. This is called channel noise of error. The amount of information sent without error is the channel capacity and the speed sent is the bandwidth of the channel (Proctor, ibid.).

1.7 Fitts Law

Cognitive psychologists adapted information theory as a means to measure human movement and reaction times to some given stimulus such as moving a hand-held mouse to a region on a computer display (Proctor, ibid.). In terms of information theory, the human is the channel where information flows. The environment or the experimenter produces some event (stimulus); the human perceives it and transmits this information as a response to the given stimulus. A shuttle engineer observing events from the control room, for example, must process a multitude of visual signals bearing on the status of the shuttle while listening to auditory messages from the test conductor concerning flight status and possible warning alarms (Neubauer, 2000). Given information in both visual and audio formats, the engineer must process the information and take the required action. The interesting metric is the processing speed or throughput of the individual. Throughput is the time required to physically move a pointing device like the mouse to the target area divided by the task difficulty (Equation 6). User interfaces can be designed (or improved) so that the user will interact with the interface quicker with fewer errors and less fatigue or stress.

Task difficulty in terms of information theory is measured in bits. Fitts called it the "index of difficulty" or ID. (Fitts, 1953) The equation is,

$$ID = \log_2 (2D/W) \quad (3)$$

where D is the distance from the starting position to the center of the target and W is the width of the target region where the movement terminates. Fitts measured the time spent by subjects who moved a stylus between two targets as quickly and accurately as possible. As the distance increased, movement times (MT) increased. And conversely, as the width of the target area increased, movement time decreased.

Fitts instructed subjects to move a stylus back and forth, tapping on marked targets. They were to tap as quickly as possible without missing the targets. He told them to "emphasize accuracy rather than speed." Movement tasks were performed using both a 1 oz. and 1 lb. stylus. Distances and widths were varied; movement times and error rates recorded. The results from this, and other studies, enabled the development of a now well-known relationship, Fitts Law:

$$MT = A + B \log_2 (2D/W) \quad (4)$$

Where "A" is the ordinate intercept and "B" is the slope of the curve. MacKenzie (1991) found using the Shannon formation of MT yielded better results and it was used in the experiment. Equation 5 is the Shannon formation of Fitts law.

$$MT = A + B \log 2 [(D/W) +1] \quad (5)$$

Error rates were 4.1% and the highest error rates occurred with the greatest distance and smallest width (the most difficult task).

Fitts Law predicts movement times using a simple linear equation where movement time is a linear function of ID. The predication equation of the linear relationship is

$$MT = A + B * ID \quad (6)$$

Figure 3 shows the relationship between MT and ID. As the task difficulty increases, time to move increases. Simply put, it takes longer to complete harder tasks. A pointing task is the combination of distance to the target and width of the target.

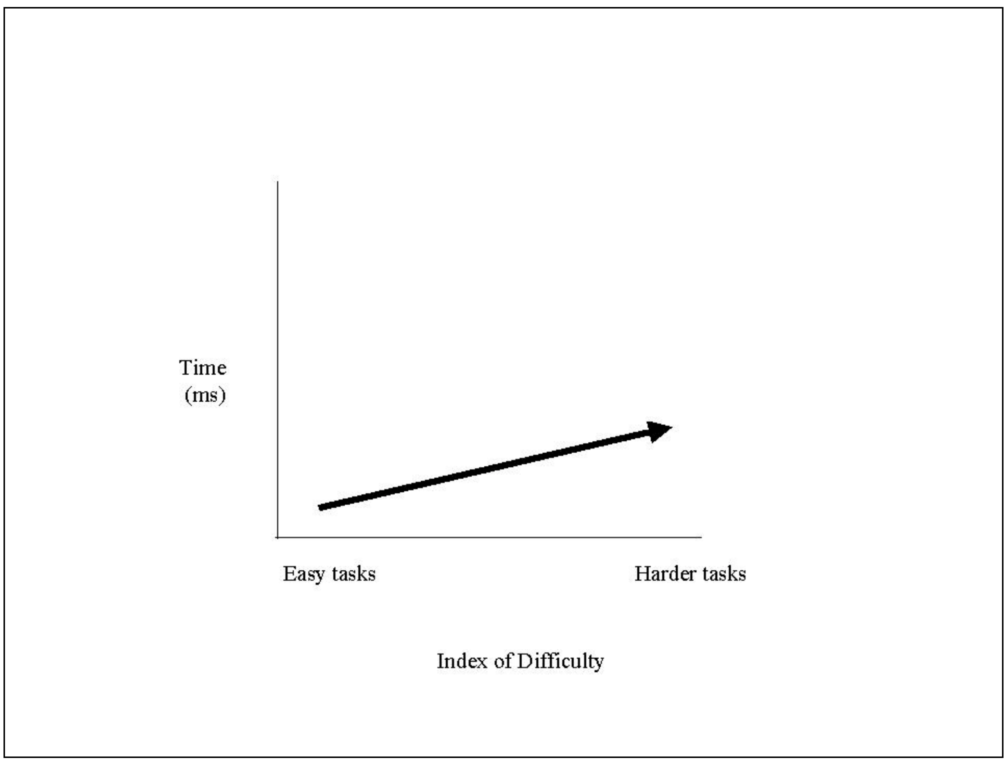

Figure 3. Movement time as function of task difficulty

If the curve intercepts the abscissa, it is the baseline (movement time) for a given pointing device. The interception of abscissa and the curve represents zero seconds, the baseline for the device. Each pointing device has a unique baseline based on how difficult the pointing device is to operate. Borrowing from information theory, task difficulty (ID) is similar to information and therefore the rate of performing tasks is the human rate of information processing. It measures human throughput (Fitts, ibid.). Fitts called throughput the "index of performance" (IP).

$$IP = ID / MT \quad (7)$$

Distance	Width	ID	MT	Errors(%)	IP(b/s)
2	2	1	180	0	5.56
2	1	2	212	.44	9.43
4	2	2	203	.08	9.85
2	0.5	3	281	1.99	10.68
4	1	3	260	1.09	11.54
8	2	3	279	.87	10.75
2	0.25	4	392	3.35	10.2
4	0.5	4	372	2.72	10.75
8	1	4	357	2.38	11.2
16	2	4	388	.65	10.31
4	0.25	5	484	3.41	10.33
8	0.5	5	469	2.05	10.66
16	1	5	481	1.3	10.4
8	0.25	6	580	2.78	10.34
16	0.5	6	595	2.73	10.08
16	0.25	7	731	3.65	9.58
		mean	392	1.84	10.10
		SD	157	1.22	1.33

Table 1. Data from Fitts (1954) tapping task experiment with stylus

Task difficulty and the rate it moves across a human channel can be compared across many differing tasks. Fitts Law has been used to compare movement times of various pointing activities as head movement (Jagacinski & Monk, 1985), foot-pedal design, working with tweezers under a microscope (Langolf & Hancock, 1975), movement times in an underwater environment (Kerr, 1973), and three-dimensional movement in virtual environments. Fitts Law although dated, is still used when measuring the processing capacity of sensory channels in human beings and is still valid when people are deprived of visual feedback (Wallace & Newell, 1983).

An example of Fitts Law without visual feedback is a study by Weiss. Weiss had subjects position a spring-loaded control stick on a target (Weiss, 1954). Subjects could not see the target until after positioning the control stick. He found that errors from position decreased as the total distance moved increased. Experimental errors (missing the target) neither increased nor decreased and the error between distances was statically insignificant.

1.8 Haptic Interfaces for the Blind

The Center for Rehabilitation Engineering Research (CERTEC) in Sweden design human interfaces for the blind. From a prototype of the game battleship CERTEC found that "...it seems like the haptic feedback was sufficient, in all but one case. Since there was no haptic feedback for the falling bomb, this confused the deaf-blind users. It is possible to translate the up, down, left and right of the Windows system on the screen into a touchable environment with the same construction and metaphors. It is a big advantage if blind and sighted Types Haptic/Tactile of devices supporting the blind user." (CERTEC)

Expanding the idea of a computer driven Braille output device Fricke (2000) recommends using a "tactile graphic tablet." Like Braille, the device is limited to a few lines of Braille at one time. Users may input pictures or feel pictures with raised-lines while icons and other graphic tools may be directly manipulated. However, the device is static display, not a haptic feedback device. Therefore, this particular interface may well benefit from the introduction of a "true" haptic feedback system.

1.9 Haptic Processing Speed

The importance of haptics in everyday life cannot be over stressed; both vision and touch give cues to spatial relationships. However, when vision is not possible, the use of haptics becomes an efficient device to obtain information quickly, like trying to find a hammer unseen at the bottom of a toolbox. The haptic channel receives information, not just sensations (Kennedy, 1992). This information is obtained across time and renders data about distance, size, and texture.

Haptic perception is an active discovery sense. Although Gibson (1966) argues that vision is also a perception system instead of just a sense, haptic perception differs from other senses in that it must explore objects in the environment instead of passively allowing information to come to it like visual information coming to the eye. Increased time is needed to "reach out" and discover haptic information. The experimental data from this research supports this claim.

Using the Fitts metric of information in bits / time (IP) or throughput, this experiment confirms haptics without visual cues is slower than throughput usually found when using a mouse.

1.10 Haptic Interfaces Overview

This section defines a haptic interface and reports on different hardware and software applications.

Application as varied as remote surgery and robot exploration have created a demand for haptic interfaces. Various commercial and prototype devices have been built.

Haptic interfaces accept user input, usually from the hand, and concurrently output a resistance or force back to the hand. Users can move in one or more degrees of freedom in "haptic space." Motion and force sensors recognize hand movements. Digital controllers allow for conversion of analog and digital signals between computer and haptic device. Two or more motors, depending on required degrees of haptic freedom, furnish the "force feedback" back to the hand. Two types of haptic interfaces are used. Either a tactile display which contacts the skin directly or a net force (force feedback) display in which interactions are felt by a tool (Srinivasan, 1997).

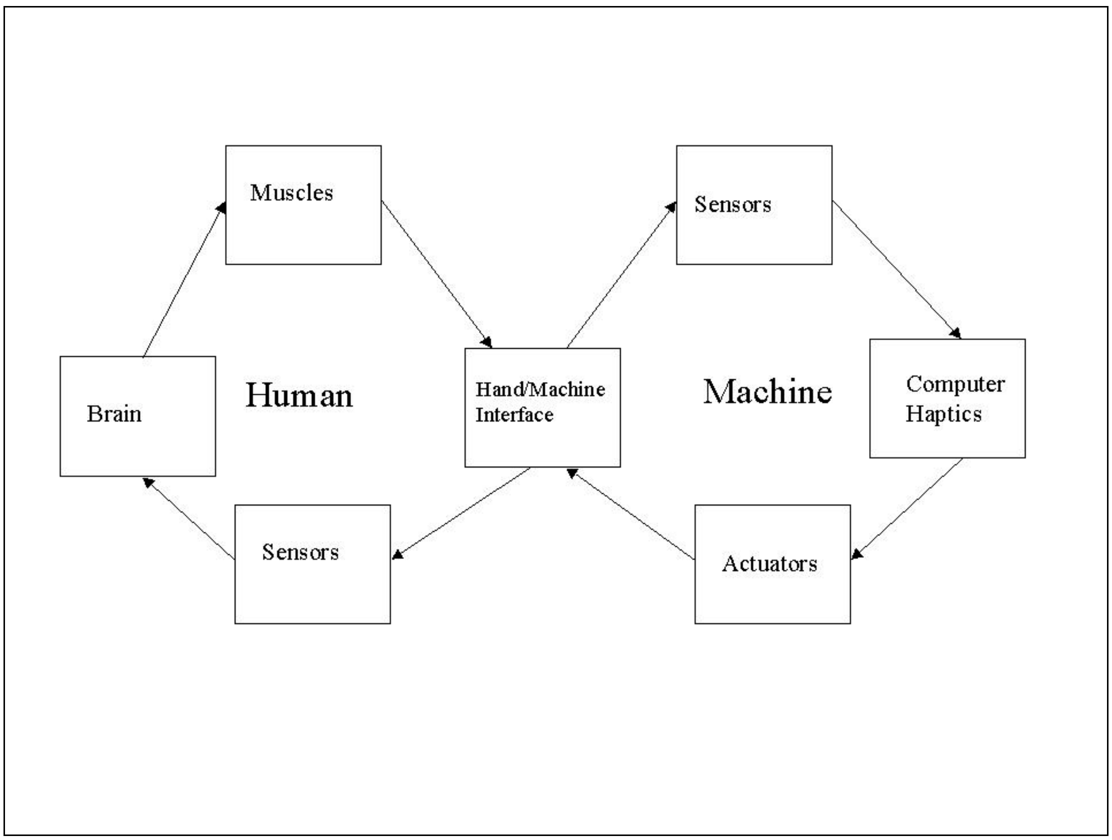

Figure 4. Haptic interaction between human and machine. (From Srinivasan, 1997)

Figure 4 is a block diagram of a haptic interface to a computer. The computer contains an algorithm and data structure describing the virtual environment or object that is to be modeled. On receiving movement direction and velocity from the human operator, the computer will generate a reactive force, which is sent back to the haptic interface where the user feels the programmed effect.

In this study, the subject decides (brain) to move the joystick (using muscles). The subject's hand moves the joystick (interface) while the joystick's sensors gather location and speed of movement and passes that data to the software (computer haptics). The software allocates the magnitude of feedback effect to the joystick. Instructions are sent to the joystick actuators to turn on the force and the hand feels the force.

The force returned to the human from the haptic interface may be exhibited by any number of different effects. Some include hitting a wall or feeling a structure that allows some "give" but returns some resistance (e.g. rubber), falling into a hole, pressing a button and many types of surface textures.

A new direction in the study of haptics simulates real-world tactile experiences in software (Rosenberg & Adelstein, 1993; Massie &Salisbury, 1994). For the purposes of this study the interest was in measuring how long a user takes to move from one effect to another. It was decided, for simplicity, to find a general-purpose effect that was easily sensed. The results of a pilot study revealed that a vibration of the joystick was the most easily detected effect.

1.11 Haptic Interface Research

This section reviews many haptics effects generated by software algorithms. Many computer graphics software algorithms are also useful when programming computer haptics. For example, when representing 3-D space collisions, the model designer is concerned with only those things that are in close proximity to the interface point; other data points are not needed for the immediate event and may be disregarded for the time being. When an object is behind another object, only the nearest object need be drawn, is another example. A final example is when navigating through a Virtual Environment (VE), an interface point (e.g. a hand) is mapped onto the 3-D coordinate system of the VE. If any virtual object comes in contact with the interface point, force is applied to the point and the user feels the object come into contact with his hand (Brooks, 1990).

Batter and Brooks (1972) showed that haptic interfaces improved learning and understanding the principles of physics. Brooks (ibid.) went on to prove that haptic displays in concert with a visual display, improved perception and understanding with a two-fold performance improvement over graphic only systems.

Robotic surgery (Borst, 2000), molecule docking, and piloting unmanned air vehicles (Draper, 2000), are examples of differing disciplines that use haptic displays for increasing productivity.

However, problems occur when using haptics with virtual environments. Users may not detect variations in roughness of virtual textures, virtual objects are bigger from the inside, and users may not understand complex objects based on purely haptic information because users have different mental models of where the virtual space is located (Colwell, 1998). Colwell discusses a problem experienced by some subjects; whenever the subject fails to find haptic input, they are said to be "lost in haptic space." On the bright side, Colwell says that haptic interfaces have "considerable potential for blind computer users." (1998)

2.0 Hypotheses

2.1 Hypotheses

If haptic hand movement time is consistent with Fitts Law, then plotting movement time as a function of task difficulty will show a positive relationship.

H1: Haptic movement time is positively related to the index of difficulty for both directions (inwards/outwards, left/right).

The classical Fitts paradigm asserts that as the difficulty of the pointing task increases, so does the time needed to move to a destination. Fitts defines the "hardness" of a pointing task by the index of difficulty or ID. For example, hitting the broadside of a barn when next to the barn is an easy task. However, a more difficult shot is aiming at and successfully hitting a small target miles away.

The independent variables were (1) ID (distance and width) and (2) direction. The dependent measures were (1) MT, (2) the X-Y coordinate the subject selected and (3) success or failure in locating the haptic target (error).

Aggregated means of movement times from all experimental subjects at sixteen different distance-width combinations were analyzed to ascertain if any linear relationship exists. With ID on the X-axis and MT on Y-axis, the mean points should form a line. A Pearson correlation coefficient will determine any relationship.

H2-A: The error rate is independent of direction.

H2-B: The error rate is dependent on task-difficulty (ID).

An error is defined as any missed target. The subject either under-shot or over-shot the target area. Data was collected for both directions. A grand mean (for both directions) and a mean for each direction were computed. The hypothesis expects no significant differences in the means for direction. Whereas, the null hypothesis (the assertion to disprove) is that the two means will not equal and significant differences will be seen between each direction.

$$H2\text{-}A: \mu(\text{Error rate direction 1}) = \mu(\text{Error rate direction2})$$

A paired t-test was performed to determine if the differences between means were statistically significant. The Paired-Samples T Test compares the means of two variables for a single group. It computes the differences between values of the two variables for each case and tests whether the average differs from 0.

The error rate by ID was computed using an ANOVA to test if the results were statistically significant. A repeated measure ANOVA analyzes groups of related dependent variables that represent different measurements of the same attribute. If the hypothesis were correct, the means across error-IDs would all equal.

$$H2\text{-}B: \mu(\text{Error ID 1}) = \mu(\text{Error ID2})=\mu(\text{Error ID3}) = \mu(\text{Error ID4})= \mu(\text{Error ID5})$$

H3: The movement time (MT) is independent of direction.

Like error rates for direction, MT aggregated grand mean times across all subjects were collected. A grand mean for time by direction was also calculated. The hypothesis expects both directional means to be equal. The null hypothesis is MT mean will be the same for both directions

$$\mu \ (\text{MT direction 1}) = \mu \ (\text{MT direction 2})$$

A paired t-test was used to check if the means differ significantly.

H4: The rate of information processing (throughput) is independent of direction and task difficulty.

A paired t-test was used to determine if the means for direction were statistically significant. Each ID was analyzed and an ANOVA run for each using the Fitts model of information theory. The haptic channel capacity was computed from movement time and the index of difficulty. It was predicted that means times across direction and task difficulty would be the same.

$$\mu(IP\ direction1) = \mu(IP\ direction2)$$

$$\mu(IP\ ID1) = \mu(IP\ ID2) = \mu(IP\ ID3) = \mu(IP\ ID4) = \mu(IP\ ID5)$$

3.0 Methods

3.1 Experimental Apparatus - The Impulse Engine 2000™

This project was performed entirely with computer-based tools. The Impulse 2000™ Figure 5 (page 24) is a haptic joystick from Immersion Inc. of San Jose, CA. The joystick behaves as a conventional joystick sending Cartesian coordinates to the computer. It is instructed by computer to apply a haptic force-feedback to the hand. The user grips the handle of the joystick which when activated, interacts with the computer to interpret the user's hand position in two-dimensional space and applies a variable resisting force. While two sensors track the hand position, the computer keeps track of virtual haptic objects. When coordinates from the joystick cross an object boundary, the software commands the Impulse 2000™ to apply a force to the joystick. The actual force felt is provided by DC-motors, which push back against the motion of the user erecting a haptic boundary. This process is carried out many times per second causing a very realistic haptic experience.

Figure 5. Impulse 2000™ from Immersion

The computer used was a Hewlett Packard™ 8123 Personal Computer. The Impulse 2000™ is connected to the computer by way of a PC interface card making for fast communication speed between computer and joystick. Software written for the experiment used Microsoft™ Visual C++ Version 6 Professional Compiler.

3.2 Description of Experimental Software

This section discusses the software written for the experiment.

Software created the haptic effects felt by the subject during the experiment. Commands to the haptic joystick enabled the haptics and were felt by the subject's hand. On feeling the haptic, the subject responded by depressing the joystick's button. The haptic target is then moved and constructed on the opposite side and awaits the subject’s input. To find the haptic target on the reverse side, the subject reverses movement direction and moves until the haptic is felt. The whole process continues until 160 trails are completed.

The software randomly selects sixteen combinations of distance and target width for each of the 160 trails. Each of the sixteen combinations was show to the subject ten times, which made up one session. The direction of movement changes (i.e. inwards/outwards from left/right) and the process begins again.

The software assumes two external actors: the test conductor and the subject. The test conductor uses a graphical interface to record subjects' demographic information and start the experiment. Once the experiment begins the graphical interface is no longer used.

Software constructs of the haptic target area as well as measures and records the time the subject requires to reach the haptic target with the joystick. Software also checks the joystick position to ascertain if the subject is inside the haptic target. Once the software senses the joysticks position is inside the haptic target area, it will send commands to the haptic joystick to invoke the haptic effect.

The joystick's working space is comprised of a two-dimensional Cartesian space of 6600 X 6600 units. The Impulse *2000*™ is a left-handed coordinate system with the positive ordinate (Y-axis) pointed down and the positive abscissa (X-axis) points to the right. When designing virtual environments (e.g. gaming) the computer display coordinates are mapped from joystick "world" coordinates. If we assume for the time being that both display and joystick use the same left-handed coordinate system, the mapping is easily calculated. For example, assume the display is a two-dimensional display encompassing 1000 X 1000 units. Controlling a display cursor from the joystick entails getting the current joystick location, converting the location to display coordinates and drawing the location on the display. The ratio of joystick units to display units is 6.6 (6600 / 1000); therefore, dividing this ratio by the joystick coordinate will transform the coordinate to display units suitable to now display on the screen.

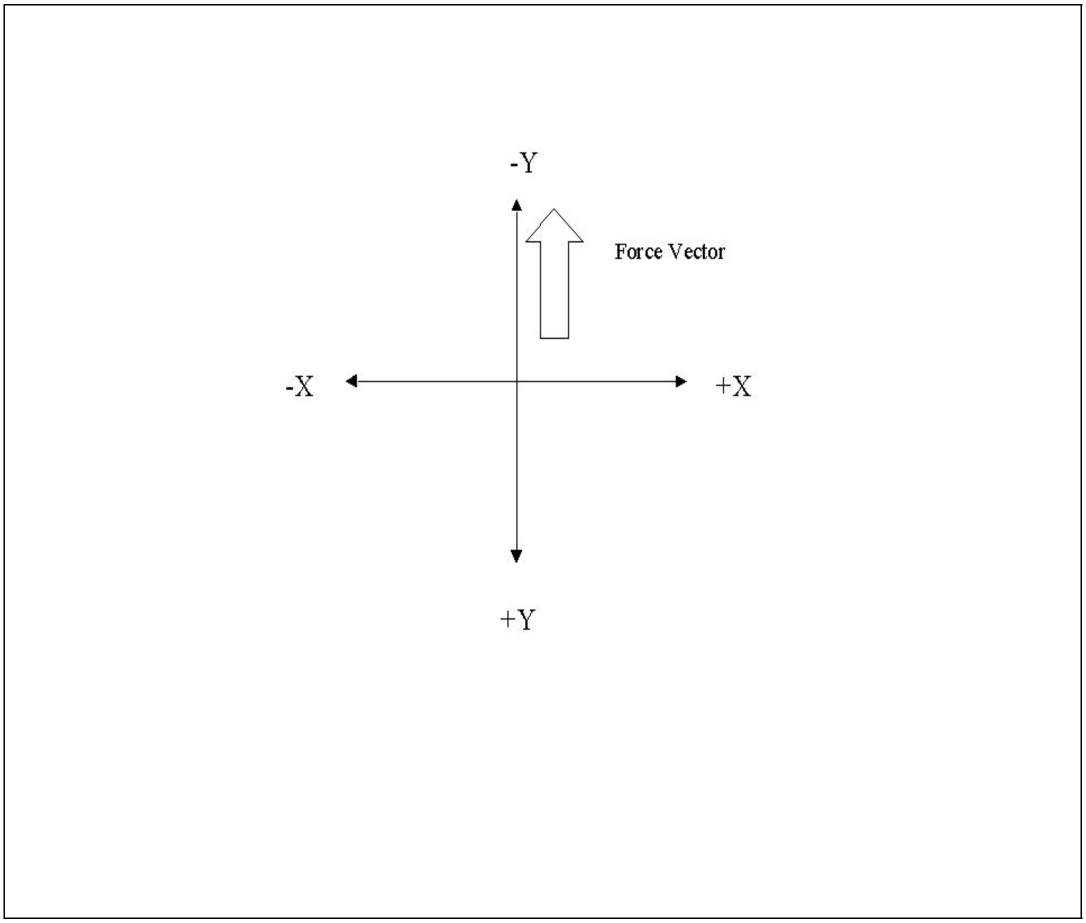

Figure 6. Setting a force-feedback vector

Force vectors are used to set the force-feedback haptic. These vectors describe a force by defining a magnitude and direction. Force vectors are passed to the haptic joystick as commands. To set an attractive force in the -Y direction, as in Figure 6, the force vector is loaded with the values (0, -500). Once the command is accepted and is carried out by the haptic joystick, the joystick handle is attracted to the -Y side of the ordinate with a force of 500. The user feels the force and either allows the joystick to move away from the body or fights back against the joystick adding an opposite force to maintain equilibrium. Software may apply force in any direction and by turning on and off forces and causing a haptic effect to be constructed.

During a pilot study prototypes of different forces (effects) were tested to achieve the best subject response (i.e., get the attention of the subject quickly). A vibration effect was chosen because it was the most detectable. The vibrating target was modeled in software. The target area is a long strip perpendicular to the direction of movement and extends the full range of joystick world space. Figure 7 (page 28) shows a point in the experiment when the subject moves their hand to the left. The width of the target is width W (in joystick units). Distance is measured in joystick units from the last clicked point to the center of the stripe. A vibration is felt as soon as the subject enters the target area.

The experiment begins when the subject aligns the joystick perpendicular to the ground (upright position) and depresses the joystick button. At the first button press event, the application translates the point where the button press occurred to the origin of joystick world-space (intersection point of the abscissa and ordinate). The first distance/width combination is retrieved in order to create the first target.

Distance D (the distance that the subject is required to move the joystick to reach the haptic target) is measured from the last joystick position (button press) to the center of the next haptic target. Width W is halved so the haptic target extends W/2 units from the center of the haptic target in each direction. Figure 8 (page 29) displays the distance and width. The haptic effect is felt once inside the target area and if the subject depressed the joystick button, it is considered a successful target hit.

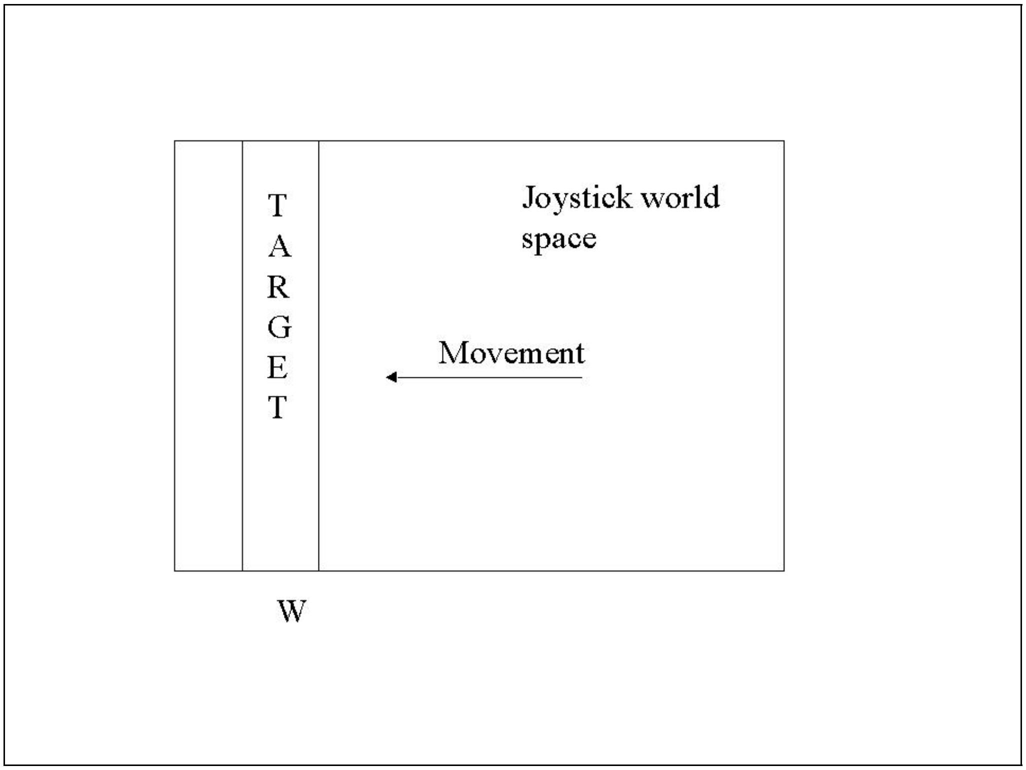

Figure 7. Moving into a haptic target

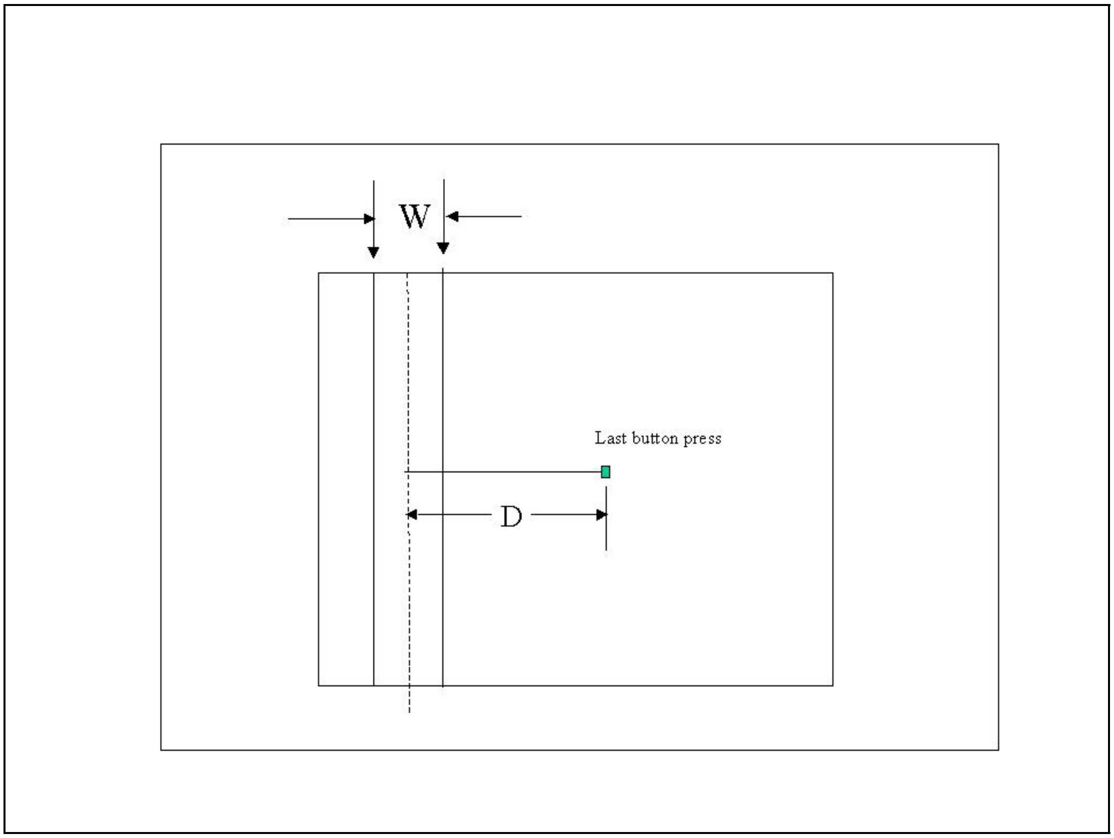

Figure 8. Computing haptic distance and width

The next D/W combination is accessed and the haptic target constructed D joystick units from the last button press *in the opposite direction*. Figure 9 demonstrates the newly constructed haptic target in the opposite direction.

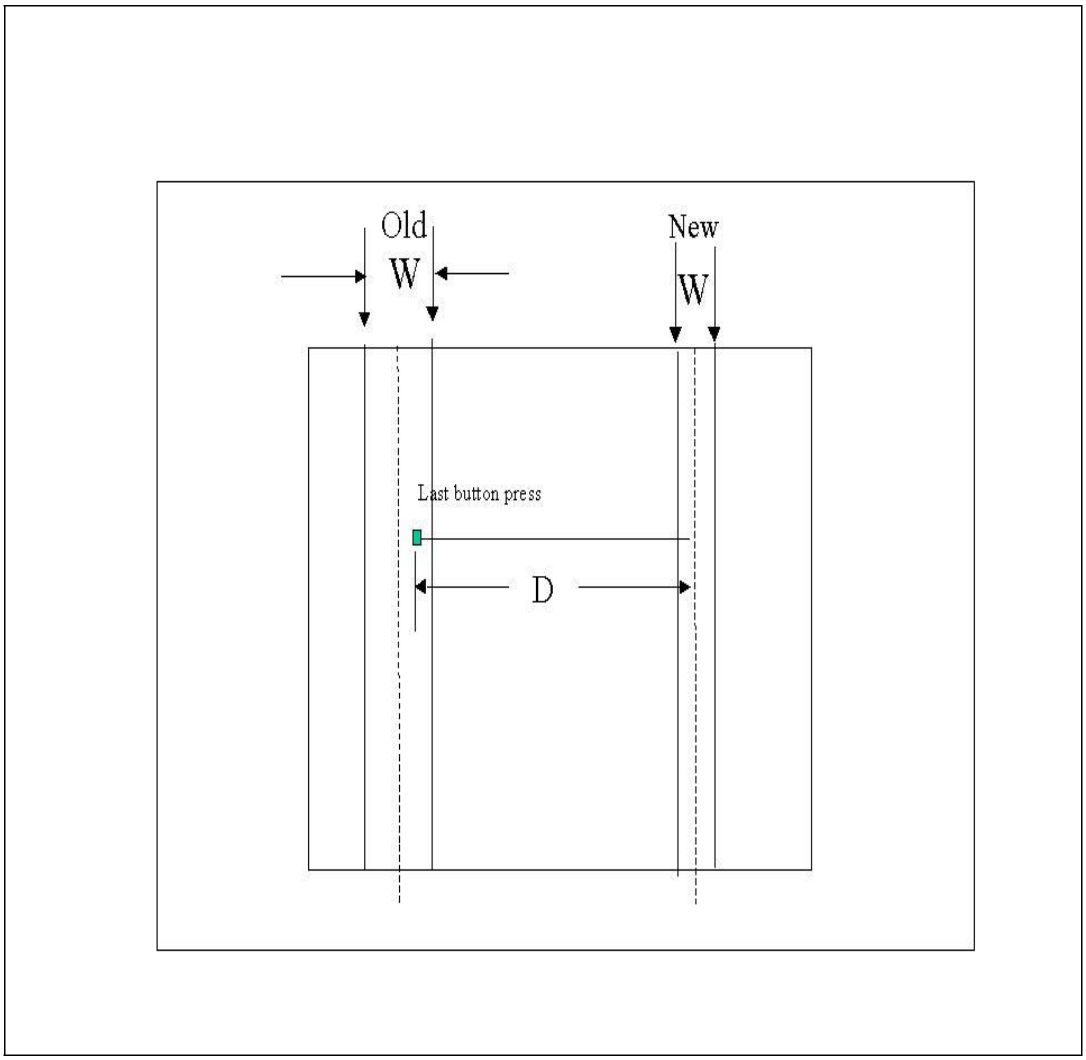

Figure 9. Computing new distance/width

The program continues until all 160 D/W trials are presented to the subject. When a subject misses the target by either over or under shooting the target, the software adjusts so the next target on the opposite side is D units from the previously selected missed point. However, if the next target is outside the joystick world-space, the variable distance D adjusts so that the target is always inside the joystick world space. Width W always remains unchanged.

To implement the software for the experiment, a joystick button listener thread (software that waits for some event, in this case a button) and a haptic effect thread were spawned. The button listener thread receives a Cartesian point from the subject and determines if the point is within the target area.

The button listener thread runs for the duration of the experiment and reports button status to a secondary thread that constructs the haptic effect. The haptic effect thread polls the device for the current joystick location. When the joystick's location is determined to have penetrated the target, software instructs the device to vibrate. As soon as the subject notices the haptic effect and presses the device's button, the haptic thread turns off the effect. Location, time, and accuracy of target selection (hit or miss) are determined and placed into a temporary buffer to be saved to disk after completion of the session for data analysis.

3.3 Describing the experimental computer haptic effect

To simulate a vibration, the haptic force needs to be applied for only a short time. Figure 10 (page 32) is an example of how a lateral hand movement by the subject creates the effect. Using the modus operator, the target region was divided into two regions; each programmed to affect a different haptic force. One force pulled the joystick perpendicular to hand movement direction and the second force had zero effect on the joystick so that the subject felt no haptic force when over the zero force region. The combination of these two forces caused the subject to experience vibration.

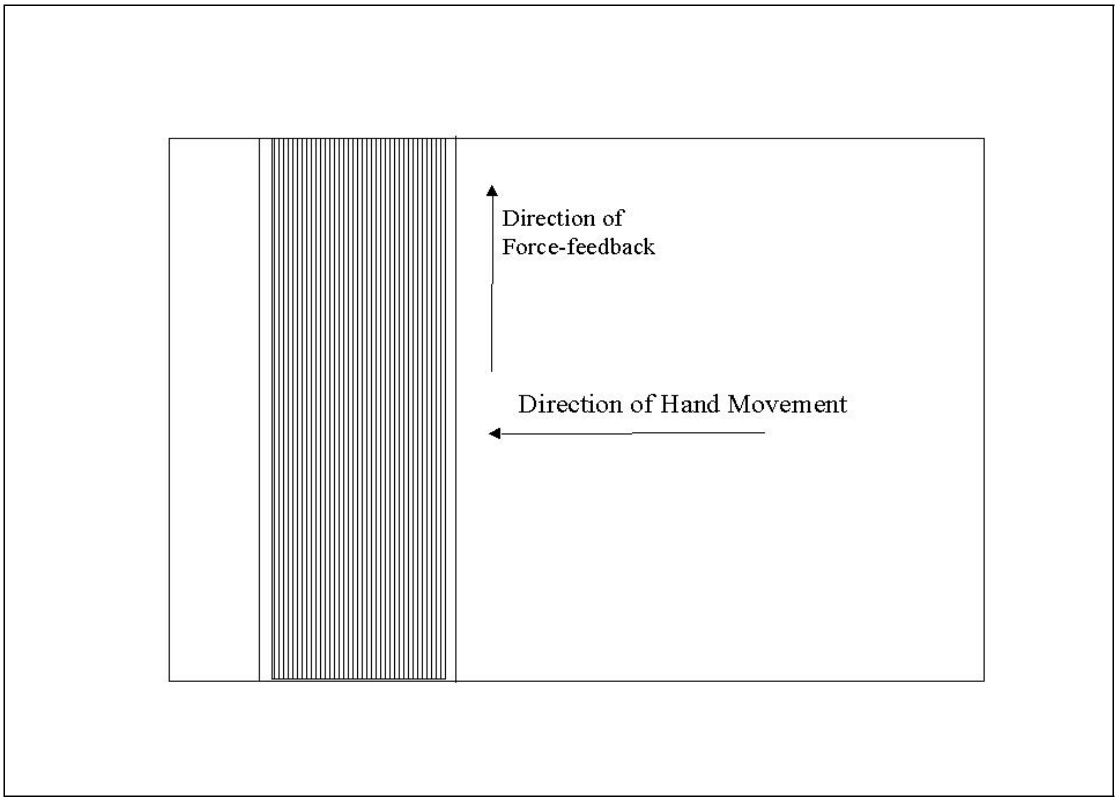

Figure 10. Vibrating haptic force

The vibration comes about because of the sensitivity of the device. Upon feeling the force, the subject attempts to apply a secondary force to counteract the haptic force. This moves the joystick back onto a zero-effect region. This region receives no force and the motors are temporarily turned off. The subject will move into the subsequent perpendicular force region, which begins again the cycle of force/no force that causes the vibrating effects. The faster the movement through the target, the faster the oscillations of vibrations will occur. Thus the subject will always feel the vibrations because of the closeness of the region. The code, which applies force to the joystick, can be found in Appendix C.

3.4 Training Period

Each participant received two warm-up practice tasks before data collection to minimize the learning effect. If unable to find the haptic target, the subject was instructed to re-position the joystick back to the upright position, press the button and continue the experiment searching for the next haptic.

3.5 Subjects

Twelve subjects volunteered to participate in the study. All were experienced with mouse use. Two had used joysticks before. Two subjects used their left hand. None had previous experience with a haptic joystick. Upon completion of all the trials, the participant was de-briefed verbally, and thanked for their participation.

3.6 Procedure

Subjects performed multiple trials on two different tasks. Before the experiment began, subjects were made aware of general joystick operation and the tasks to be completed. The two tasks were a left/right horizontal movement task and an inwards/outwards vertical movement task. All sat in front of the joystick with the joystick resting on a table. Subjects choose to grip the joystick either with the right or left hand. The subjects' task was to move the joystick in a lateral or inwards/outwards fashion until a vibration was felt. This vibration indicated that the subject was on the haptic target. The subject pressed and released a button built into the grip-handle of the joystick. The vibration would stop and the subject would begin locating the next haptic target by reversing direction. The distance and width of haptic presentations were randomized by software. No visual cues were available to make a more accurate choice; however, an audio side effect of haptic vibration was present.

Subjects were instructed to aim accurately for the target and move to the next target after pressing the joystick's button. The lateral task occurred before the inwards/outwards task. Subjects rested a few minutes between tasks.

Widths were divided into 250, 375, 500, and 1000 joystick units. Distances were 1000, 2000, 3000, and 4000 units. Targets were perpendicular to movement direction. The target appeared as a strip perpendicular to the subject's movement and would span the entire length of joystick world-space. The joystick was positioned to the upright position to begin each session. The subject was told the first target was to the right of the starting position. To begin the test, the subject depressed the joystick button and moved to the right until over the vibrating haptic target, depressed the button once more and began moving left until over the next target. The subject stopped the test when instructed to do so by the test conductor.

3.7 Experimental Design

The experiment was a 2 X 4 X 4 fully *within subjects repeated measures* (a score is obtained for each subject at each level of the independent variable) experiment. Controlled variables were tasks (two levels: lateral and inwards/outwards), target width (four levels), and distance (four levels). Distances and widths were in joystick units. Dependent variables were movement time (MT), error rate (computed from the subject selected coordinates), and the index of performance (IP = MT/ID). Movement time was measured from the button-down action event to the next button-down action event. Measurements were aggregated across subject resulting in one data point for each level of the independent variable.

Each task (one in each direction) consisted of 160 trials where each trial was a single move of the joystick to a haptic target and a press/release button action. Each one of the sixteen distances and width combinations were presented in random order and occurred ten times each for a total of 160 trials. After the two sessions, the subject had completed a total of 10 X 2 X 4 X 4 = 320 trials.

Fitts' experiments used four levels for target amplitude (distance) and target width (distance = 2, 4, 8, & 16 inches; width = 1/4, 1/2, 1, & 2 inches) that tested IDs from 1 to 7 bits. The design for the experiment was similar but used joystick units that tested IDs from 1 to 5 bits.

4.0 Results

4.1 Introduction

The main purpose of this study was to investigate haptic performance and suggest how a haptic interface could be constructed to aid in graphic window navigation, most notably for sight-impaired users. The results show promising findings. Movement time of a haptic joystick was consistent with Fitts Law.

The data was sorted and a pre-analysis performed using Microsoft Excel™ 97. SPSS™ for Windows release 10 was used for data analysis. Adjustments to the data were made to eliminate data outside two standard deviations from the mean.

To determine if a correlation exists between mean movement time (MT) and task difficulty (ID), mean movement time by subject and ID were entered into a SPSS file and analyzed using the Pearson correlation.

To determine if mean movement times between directions differed, the mean movement time by ID was entered into a SPSS file by direction and ID. These means were analyzed using the matched sample two-tailed t-test, with a Alpha equal to .05.

To determine if mean movement times between directions differed, the mean movement time by ID was entered into a SPSS file by direction and ID. These means were analyzed using the matched sample t-test, with a Alpha equal to .05.

To determine if errors by direction differ, the mean error rate by subject was entered into a SPSS file and these means were analyzed using the matched sample one-tailed t-test, with a Alpha equal to .05. Mean error rates by ID were computed and entered into SPSS. Once the mean for each ID was obtained, a matched samples t-test was run on the means to determine if there were significantly more correct target hits in the inwards/outwards direction than with the left/right direction. An ANOVA repeated measures analysis was used to determine if the error rate by ID differed significantly.

Throughput means by subject and direction were computed and entered into SPSS. To determine if one direction was significantly more efficient than the other, a matched samples t-test was run on the means. An ANOVA repeated measures analysis was used to determine if the throughput was significantly different.

4.2 Hypothesis - MT is positively related to ID

H1: Haptic movement time is positively related to the index of difficulty for both directions (inwards/outwards, left/right).

A linear relationship exists between the dependent variable movement time (MT) and the independent variable index of difficulty (ID). A scatter plot of means IDs with associated times is shown in Figure 11 (page 38). A positive Pearson correlation was found ($r = 0.718$, $p < 0.01$). However, most Fitts experiments result in a Pearson correlation of $r = 0.9$ or greater (Mackenzie, 1991). A close examination of the data in Figure 11 displays two independent clusters of points.

Table 2, in Appendix A lists the mean data points. All the points in the upper left belong to distances that are equal to 1000 joystick units. The four points on the left form a nearly straight line with $r = 0.989$, $p < 0.05$. The remaining points have a Pearson correlation of $r = 0.928$, $p < 0.01$. Two linear relationships exist: One for distances of 1000 units and a second for all other distances.

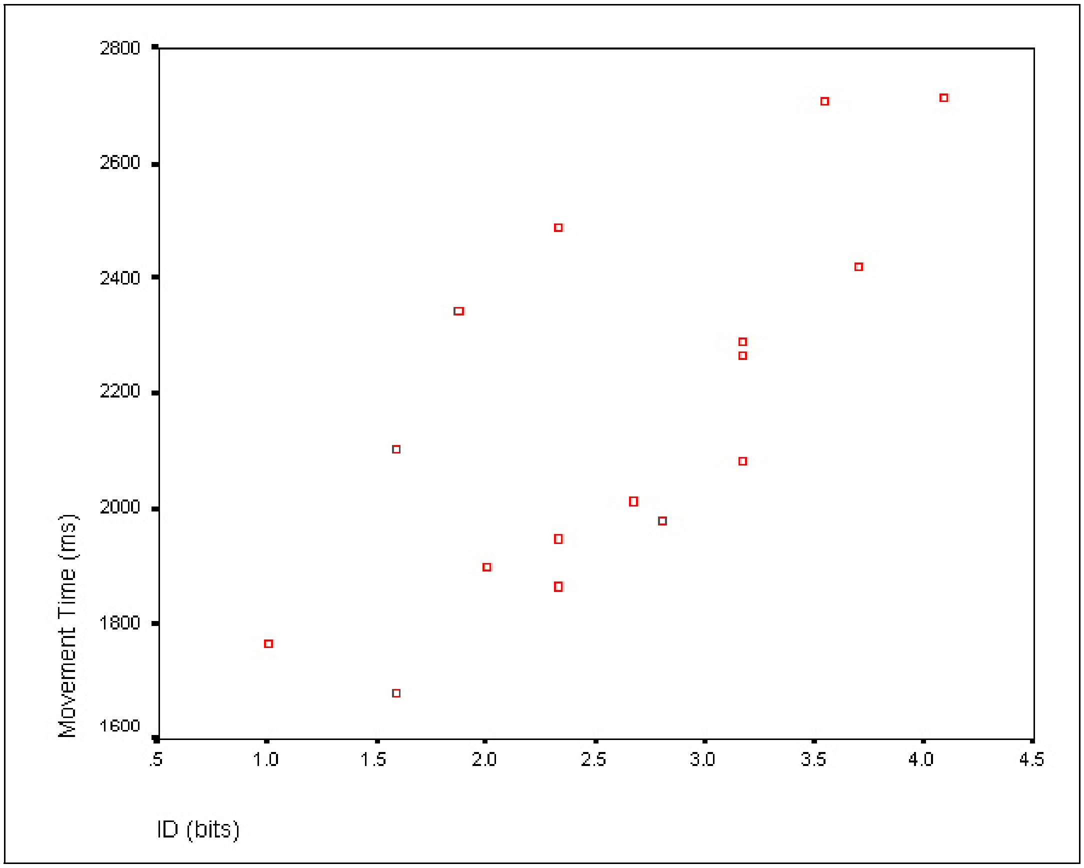

Figure 11. Scatter plot of MT as function of ID

The steeper slope for distances of 1000 units indicates that as the task (in this case the target width) becomes more difficult, the time needed to move the joystick will quickly increase as width decreases. Width quickly makes a larger influence for distances of 1000 compared to the other distances. This indicates an optimal target width. Targets should be greater than 1000 units.

The trend line is steeper for the cluster of data forming the line (where Distance = 1000). The steeper slope indicates longer time is needed to accomplish moving small distances in haptic space without any feedback. More movement time is needed when doing close-in work. In covering smaller distances, the subject overshoots the haptic target because it comes up too soon and is required to stop and reverse direction to regain the haptic target.

Haptic interface designers must take the short distance problem into consideration when designing small distances moves in haptic 2D space. To save time, an audio cue could signal target closeness helping to prevent the subject from missing (over-shooting) the target and returning.

The H1 hypothesis was supported. Haptic movement time was slower when compared to visual feedback but it is consistent with Fitts law. Haptic movement times are predictable using Fitts unless short distances are used. Short distances have longer movement times. At least two different MT-ID relationships exist and designers must be aware of the different MT-ID relationships when doing close-in work.

4.2 Hypothesis - Errors rates influenced by direction and difficulty

H2A: The error rate is independent of direction.

H2B: The error rate is dependent on task-difficulty (ID).

An error was selecting outside the haptic target area (non-vibrating). The error rate grand mean was 21.5%. This is a very high error rate when compared to the original Fitts experiment, which were only 4%. However, the error rate is not disproportionate when considering other non-visual feedback movement time experiments (Meyer, 1988).

Error rate for inwards/outwards task was 22.9% and left/right pointing was 19.3%. No significant effect for direction was found. Hypothesis H2A is supported.

There was a significant effect for width of the haptic target ($F_{(3,188)} = 8.452$, $p < .0001$). Accuracy improves with a wider target (Figure 12). Error rates for distance did not change significantly. Hypothesis H2B is supported.

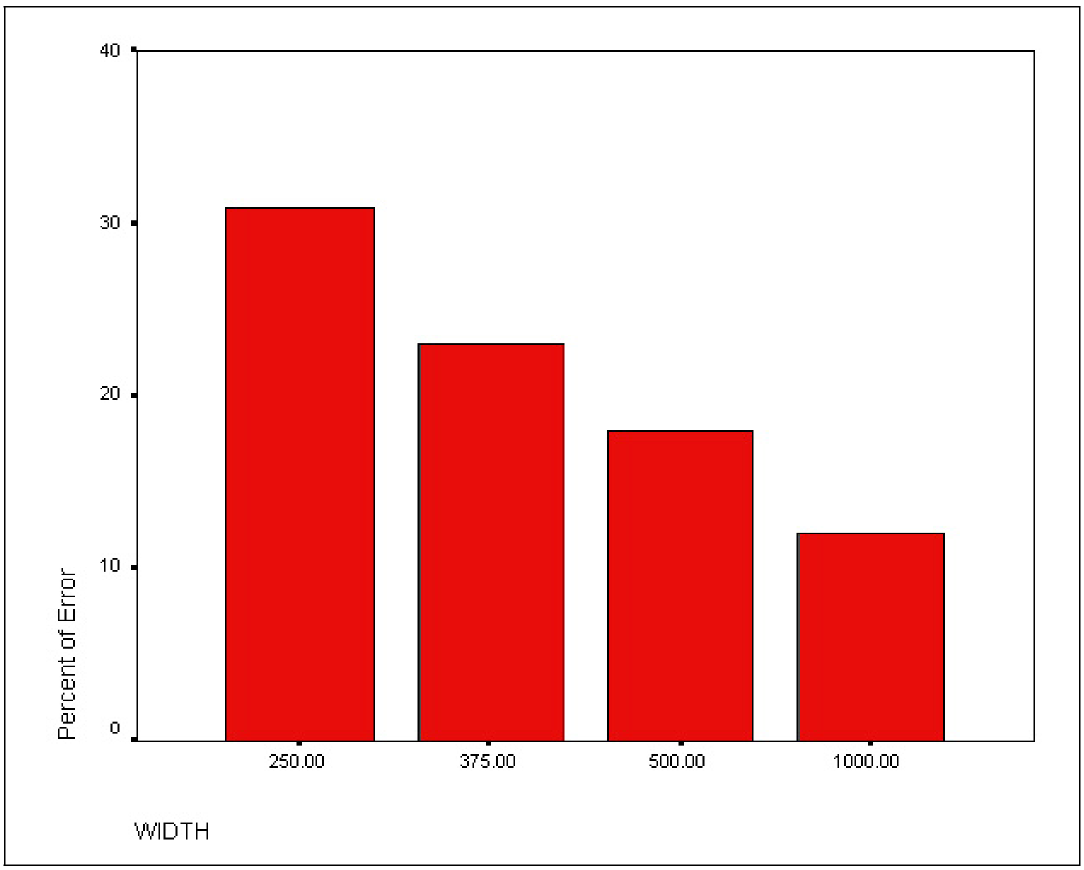

Figure 12. Percent Error by Width

As the level of difficulty increases, so does the error rate. The error rate for ID was also significant $F_{(10,181)} = 3.952, p < .05$.

The error rates increased as ID increased. Hence, the hypothesis that the error rate is dependent on task-difficulty (ID) is accepted for ID. Width, not distance, influences the error rate. Figure 13 (page 42) is a scatter plot of ID by percent of error. The data was found to have a correlation of 0.71. The regression equation was

$$\textit{Error rate} = 5.6 + 6.4ID.$$

The error rate is much better when compared to the expected random error. The expected random error is the probability of hitting the haptic target without any feedback, visual or otherwise. The probability of randomly selecting a target correctly is width of the haptic target divided by the whole haptic space in one dimension.

$$P = \frac{(W)idth\ of\ target}{Haptic\ space}$$

Since haptic world-space is 6600 square, the probability for each of the four W combinations is P(W1) = 3.8%, P(W2) = 5.7%, P(W3) = 7.6%, P(W4) = 15%. The error rate for each W is 32%, 24%, 18%, and 13%. The success rate for each W is 68%, 76%, 82%, and 87%. Clearly, the success rate far exceeds the expected probability.

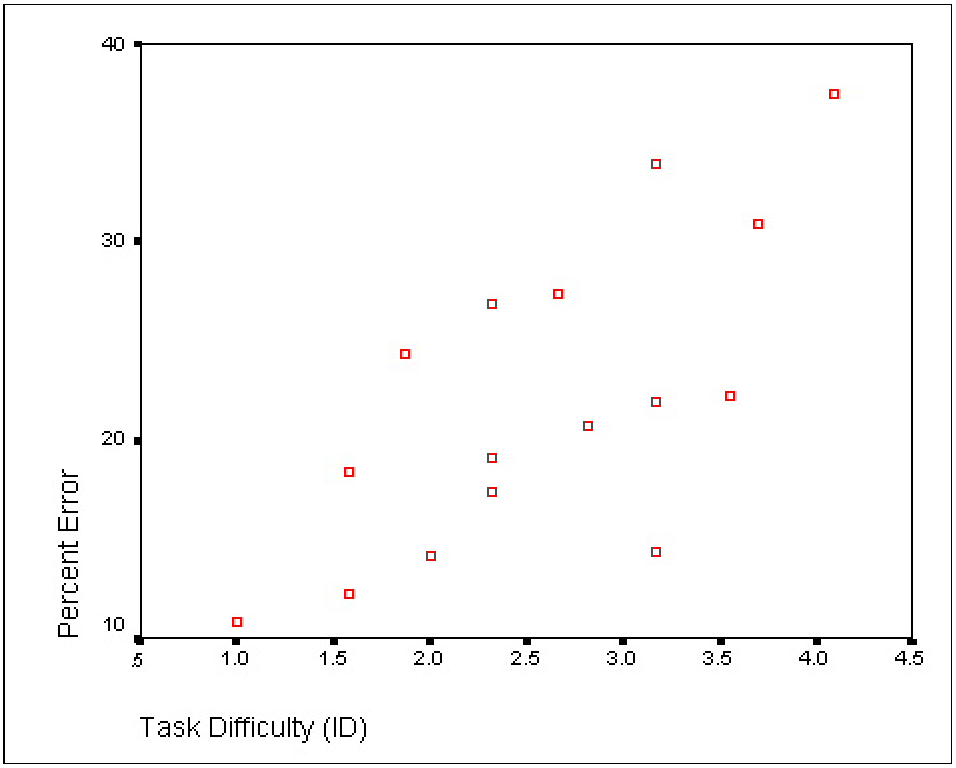

Figure 13. Percent error by task difficulty

The hypothesis that error rate is independent of direction is supported. The second part of the hypothesis that error rate is dependent on task difficulty is also supported.

4.3 Hypothesis - Movement Time is independent of direction

H3: The movement time (MT) is independent of direction.

The grand mean for movement time was *2160* ms. Grand means across direction (inwards/outwards and left/right) are 1970 ms and 2268 ms respectively for movement times. There was a significant main effect for direction, with inwards/outwards movement faster than left/right movement ($t = -4.012$, $p < .002$). The hypothesis that movement time is independent on direction is rejected.

4.4 Hypothesis - Throughput is independent of direction and difficulty

H4: The rate of information processing (throughput) is independent of direction and task difficulty.

The grand mean for performance or throughput was 1.404 bits/seconds. Left/right movement was 1.295 bits/second and inwards/outwards was more effective at 1.499 bits/second. There was a significant difference between throughput direction ($t = 4.772$, $p < .001$). Figure 14 (page 44) shows throughput as function of ID.

There was a significant difference of ($F_{15,165} = 14.923$, $p < .001$) between IDs. Figure 16 is the observed IP values by ID. The Pearson correlation coefficient was $r = 0.76$.

The rate of information processing is independent of direction but not of task difficulty. The hypothesis is not supported.

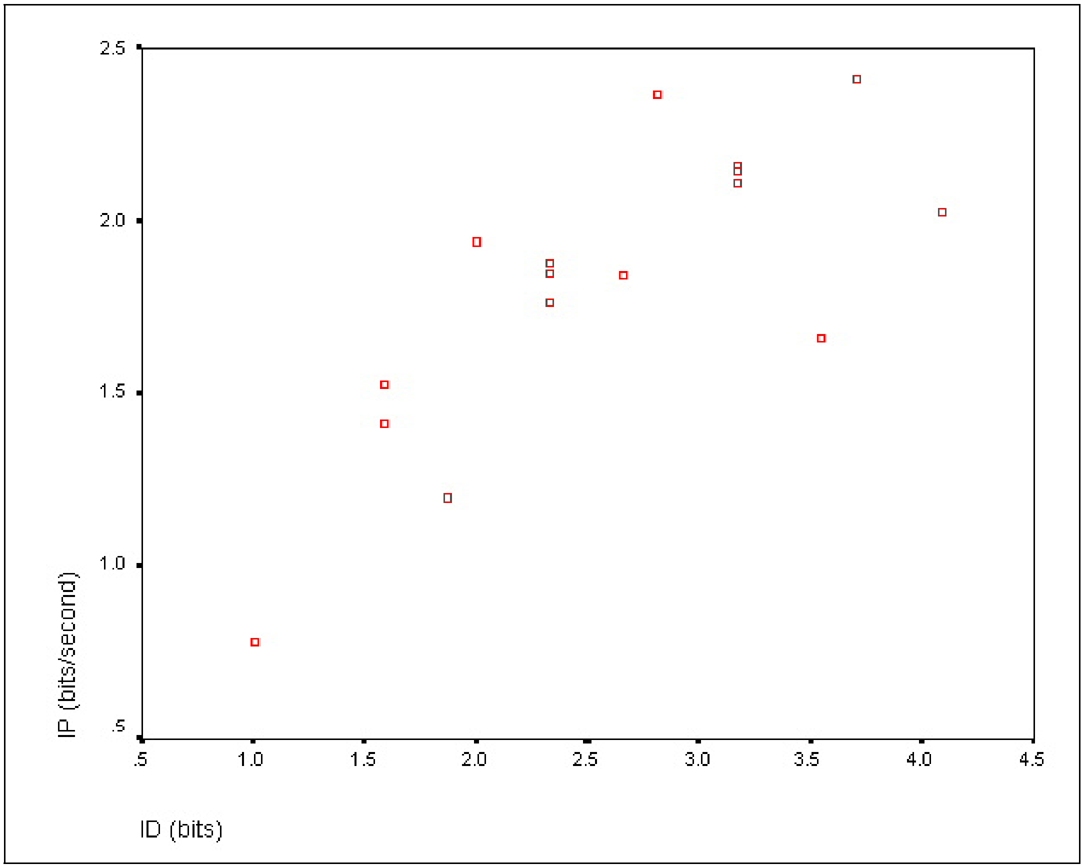

Figure 14. Throughput as function of Index of Difficulty

5.0 Discussion

This research has examined the power of Fitts Law to predict movement times using a haptic joystick without vision cues. Two experiments (directional) were conducted to test the model's performance under different task conditions.

Unlike a visual target, the subject must be inside the target to feel it and realize the location of the haptic target. Visual cues (graphical targets) inform as to location and distance. Given visual cues, users know they need to move the pointing device the given distance and direction to capture the target. Since the subject in this study received no hint as to target location except direction, acceleration of joystick movement is constant. The subject knows the direction of the target and moves in that direction but does not know the distance to the target boundary; it could be close or far. The strategy is to move the joystick a constant rate until the haptic is felt. More research is needed to look at the velocities of target capture. Is the capture similar to graphical targets where a movement is many sub-movements until the user is confident the cursor is over the target?

Most subjects in this research reported that they repeated the haptic region by entering, then exiting, and then once more re-entering the region, as if they needed to repeat the haptic to confirm that the experimental haptic vibration was there by going to a non-vibrating region and then returning to the vibrating region.

Some subjects were observed to purposefully find the haptic area, go over it to a non-vibrating area, and then return back to the haptic assured that the target was captured successfully. If returning to a target was needed for capture confirmation, more time was needed for all distance/width combinations. Perhaps the reason the smallest distance was most time consuming is because by the time the subject finds the haptic target, they travel though the haptic target to the other side and lose the force-feedback, forcing the subject to a full stop. Once stopped, the subject no longer feels the haptic and must reverse direction. Additional time is added to the "exploration" time increasing the total time needed for moving small distances. Since the target is small, it is different to find and capture. Movement times between directions were shown to differ significantly. The kinesthetic effect of the hand is a possible explanation for the difference in movement times.

Error rates were overall much greater than Fitts original study but Fitts original study was a visual study. The error rate was better than other non-visual research. Because this research failed to give the subject a hint as to closeness of the haptic target, more research is needed. It is likely that error rates would fall given the explanation above. The pre-movement hint could be either auditory or haptic. If haptic, a directional (gravity) force could help the subject locate the target. The amount of the pulling force would telegraph the distance to the haptic target; the stronger the force would signal the proximity to the target.

Haptic information is slower to process than visual information. This is not surprising since other haptic activities, for instance Braille reading, is slower than visual reading (Heller, 1991). Vision, in contrast, has a large field of view where more information can be quickly obtained and processed; touch is limited to a much smaller field of view. Therefore, touching requires more time to receive environmental information (e.g., shape, texture, etc.) because the environment must be actively explored. This is in contrast to visual processing, where, because of the larger field of view, more information is available quicker.

This is similar to what some subjects reported after the experiment. They entered a haptic target region, exited, and once more re-entered the area. This suggests that the subject needed to repeat the haptic experience as if they needed to make sure by discrimination it was the vibrating target. They were exploring and regressing or repeating the target area. Throughput also was better moving outwards instead of left/right. Since movement time was faster for moving outwards, better throughput is also found in the same direction because movement is related to throughput (IP =ID / MT).

Since the intended application of haptic interfaces is for the sight-impaired, it would seem logical to presume that, given their unique challenge of performing in a visually rich environment, they would be more accurate than the subjects in this study. Therefore, research is needed to discover if the intended audience will benefit from a haptic only interface.

Haptic displays and haptic software can use the Fitts paradigm for evaluation of user interfaces. When designing haptic interfaces the developer must be aware of more than one movement time-task difficulty relationship and other task effects. Understanding the differences in tasks will improve the interface. Despite the fact that the error rate was high when compared to visual feedback, it was much greater than the expected value from guessing. Perhaps with more training and use of haptic interfaces, accuracy will increase. Accuracy remains a problem to fully substitute haptics for graphics. However, this research demonstrates that Fitts can be used as a predictive tool.

Movement times were found to be a linear function of the index of difficulty except when distance was equal to 1000 units. Correlation was similar to other visual Fitts experiments, suggesting larger haptic distances can be used to replace graphical targets. The granularity of moving a small distance and a small width impacted the movement time. The increased time for moving small distances may be caused by subjects needing to "repeat" a target by passing over the target and returning a second time to the target. This serves to confirm that the subject felt the haptic. Error rates for this condition were not significantly different from the grand error rate.

Some experimental side effects were observed, which could introduce unexplained results. The targets, as mentioned previously, were made perceptible by vibration when the subject moved the joystick and entered target region. When the joystick was over a haptic target a slight audio sound was produced a result of the motors being activated. This effect could possibly have the effect of helping the subject find the target. In addition, whenever an under or overshot error occurred, the distance had to be computed to fit into joystick world-space. Most times this worked well; however, sometimes the target was moved so it resided on the edge of the joystick's world-space. Possibly hard to feel and compare to non-haptic spaces, especially smaller widths.

Nonetheless, Lederman and Klatzky have shown that haptics involves two systems: cutaneous and kinesthetic.

The research hypotheses are summarized below with a brief statement of the outcome regardless of direction.

H1: Movement time is positively related to the index of difficulty for all task combinations.

Haptic targets without a visual cue was found to obey Fitts Law. Hypothesis H1 is supported.

H2-A: The error rate is independent of direction.

No significant effect for direction was found. Hypothesis H2A is supported.

H2-B: The error rate is dependent on task-difficulty (ID).

Error rates for distance did not change significantly. Hypothesis H2B is supported.

H3: The movement time (MT) is independent of task.

Rejected. Vertical movement was found to be faster than lateral movements.

H4: The rate of information processing is independent of task.

Rejected. Vertical movement had an increased rate of information.

The goal of the study was to affect a haptic function and make some statements about the best way to present haptics to the sight-impaired and users in general. The haptic joystick interface was found to follow the Fitts' paradigm. Movement times were found to be a linear function of the level of task difficulty. Haptic interface designers should use Fitts when choosing placement of virtual haptic targets. However, two liner relationships were found when measuring movement time in a non-visual haptic environment. The first when the joystick traveled the smallest distance and the other with all other distances. Therefore, haptic targets, unlike visual ones, will take longer to move the joystick and recognize the haptic targets that are placed close to one another. This optimal range was found to improve by increasing the movement distance to more than 1/3 of joystick space.

Brooks has shown that combining sight and haptics in a virtual environment increases the learning experience, in the same way combining more sense modalities should increase the human computer interface. Combining both sense modalities should improve error rate and movement time, which would make haptics a variable tool for the sight-impaired.

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Appendix A

Summary Tables

Distance	Width	MT (ms)	ID (bits)	%Error	IP
1000	250	2488.59	2.321928	26.92	1.7625
1000	375	2344.54	1.874469	24.33	1.1998
1000	500	2103.95	1.584963	18.42	1.4171
1000	1000	1765.08	1	10.75	0.781
2000	250	2289.54	3.169925	33.92	2.1674
2000	375	2011.95	2.662965	27.42	1.8407
2000	500	1949.75	2.321928	19.17	1.8779
2000	1000	1680.13	1.584963	12.25	1.526
3000	250	2419.79	3.70044	30.83	2.4101
3000	375	2267.08	3.169925	21.92	2.1095
3000	500	1980.54	2.807355	20.75	2.3651
3000	1000	1900.28	2	14.17	1.9416
4000	250	2714.73	4.087463	37.42	2.0294
4000	375	2707.23	3.544321	22.25	1.6624
4000	500	2085.77	3.169925	14.42	2.1427
4000	1000	1864.23	2.321928	17.33	1.8457
	Grand	2160.82	2.582656	22.02	1.8174

Table 2. Distance/Width combinations

Appendix B

Statement read to subjects before experiment

This experiment uses a force feedback joystick. When you move over a spot, a force is sent to the joystick. There will be two tests with the joystick: this will indicate that you are over a target. There are two targets one of the right and the second on the left. You will press the joystick button when you are one a vibrating target. This will turn off the vibration effect.

After, you will move as quickly as possible without errors to the opposite side. In this case you would move form the right to the left side. Errors not noticed. They occur when you press the button when not over the vibrating target area.

The movement distances both left and right will change. Some will appear to be short while others will be close to the edge of one of the side's of the joystick. If you move and do not feel a vibration, continue moving to the edge and then go back in the opposite direction until you feel the vibration. Still, after going in the opposite direction, no vibration, center the joystick in the center upright position and click the joystick button and continue searching for the next vibration.

When the right/left trials are complete, we will start the forwards/backwards trials. These will have a similar vibrating effect; however. You will find them by moving backwards and forwards instead of to the right and left.

Before the real trials start, we will practice with a training session to introduce you the device and its effects.

Let’s start the training. Position the joystick by centering it upright. When you are ready to start you will press the joystick’s front button. The practice is then started and the first target will be on the right. I will inform you when the practice is complete.

Now let’s practice the backwards/forwards trial. Position the joystick by centering it upright. When you are ready to start you will press the joysticks front button. The practice is then started and the first target will be in the backwards position. I will inform you when the practice is complete.

All right let’s start the first right/left trial. Position the joystick by centering it upright. When you are ready to start you will press the joystick’s front button. The trial is then started and the first target will be on the right. I will inform you when the trial is complete.

Let’s start the backwards/forwards trial. Position the joystick by centering it upright. When you ready to start you will press the joysticks front button. The trial is then started and the first target will be in the backwards position. I will inform you when the trial is complete.

Appendix C

Sample code that applies a force to the joystick.

The joystick will be attracted to the-Y axis.

Example of Right/Left target effect:

```
void CFeedbackDlg::mEffectRL()
{
gX = g_pDlg->mGetXPosition();
// is x in force field?
if ((gX > gWRSide) &&(gX < gWLSide))
{	g_pCurrentDevice->EnableMotors();
	if ( (gX % 12) < 6)
	{
		g_DACOut[1] = -1000;
	}
	else g_DACOut[1] = 0;
}
else
{
	g_DACOut[0] = 0;
	g_DACOut[1] = 0;
}
g_pCurrentDevice->OutputForces(X_AXIS | Y_AXIS | Z_AXIS, g_DACOut);
}
	return;
}
```