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A STUDY OF LEARNING IN THE OPERATIONS OF A VISCOUS DAMPED TRAVERSING UNIT

A THESIS

Presented to

The Faculty of the Division of Graduate Studies

by

Geoffrey Alan Robinson

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Operations Research

Contract No. DAAG39-77-C-0041

Georgia Institute of Technology

June, 1978

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6 93 p.

A STUDY OF LEARNING IN THE OPERATIONS OF A VISCOUS

DAMPED TRAVERSING UNIT

Approved:

Thomas L. Sadosky

Thomas L. Sadosky, Chairman

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Date approved by Chairman MAY 17 1978

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Finally I would like to express special appreciation to my wife, Donna Pardue Robinson, and my children, Kristin, Keith and Stephanie for their patience and moral support throughout the duration of this project.

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SUMMARY

Tracking studies concerned with the performance of a human operator attempting to track a point on a form of visual display have been conducted extensively. Few studies have been concerned with the learning of trackers in a field environment. The objectives of this study were to investigate learning of persons doing a tracking task and to find the measure of performance which most accurately describes learning.

A review of current literature was helpful in discovering earlier methodology, approaches, experimentation, generally accepted measures of tracking error, measures of learning and previous conclusions. Successes as well as problem areas and errors were revealed This data was utilized as a basis for the experimental design and analysis used in this research.

The apparatus to be used by the subject trackers and the data collection devices were of exacting manufacture. Experimental error was held to a minimum by careful controls. Angular velocity was held constant. A black circular target with white crosshair was used.

Data was analyzed to compute several statistics. Performance was measured by the number of tracking reversals, number of tracking crossovers, range of errors, mean error, standard deviation of error, standard deviation of error adjusted for autocorrelation and autocorrelation coefficients. Computer drawn histograms of the data aided in the analysis.

The results were that learning was noted in all trackers. Learning was accomplished in the first ten trials, after which performance plateaued. Standard deviation of error in the horizontal direction was the best measure of learning. Tracking error was affected by autocorrelation. Three subjects showed no significant difference in their standard deviations of error at the end of the experiment.

CHAPTER I

INTRODUCTION

The purpose of this study was to investigate the learning of operators who optically track targets using a viscous damped traversing unit. The viscous damped system was designed to overcome human instabilities such as tremor and thus improve overall tracking performance. The mount used dampers mechanically coupled to the traversing unit. Most of the high-frequency manual tracking errors (oscillations) which occur at frequencies greater than one hertz were filtered out by these dampers. The damper consisted of rotating disks and stationary disks. A high viscosity fluid lies between the rotating disks and the stationary disks. This fluid was one whose resistance to shear increased as the velocity gradient between the rotating and the stationary members increased. A torque was applied to the rotating member of the damper in order for the operator to optically track a moving target using this type of mount. Although the tracking system used in this study was operational on current military systems, human learning performance with this sytem had not been investigated.

The project was proposed by the U. S. Army Operational Testing and Evaluation (OTEA) during a recent visit to Georgia Tech. This project provided useful information to OTEA for the evaluation and training of trackers who use this system on line of sight-wire-guided missile systems. The U.S. Army Human Engineering Laboratory at Aberdeen

Proving Ground, Maryland was also interested in the project and supplied the viscous damped tripod and other necessary equipment.

The problem was approached initially through the exploration of existing literature and examination of associated work in this area. Since previous wrok on viscous damped units measured the errors of trained trackers, it became necessary to perform experimentation on untrained subjects. Four subjects were used as trackers. Data was collected using a special camera and sight mounted on the tripod. Analysis of the film as accomplished using equipment availabe at the Army Human Engineering Laboratory and at Georgia Institute of Technology.

For each analyzed trial a series of performance measures were calculated. In both the horizontal or X and the vertical or Y directions, a computer program computed such statistics as mean error, standard deviation of error, range of error and number of tracking reversals.

CHAPTER II

LITERATURE REVIEW

General

There has been a great deal of interest and study in the modeling of human performance in tracking tasks. Human performance has been examined by means of mathematical models and computer simulation in attempts to predict tracking results consistent with results from use of the actual system. These models and simulations have for the most part dealt with the tracking of point targets, that is the correlating of a small or single point target with a single point or small cursor response. In general, these studies measured error as a hit or a miss. Time on target was considered a correct tracking response and time not on target was considered an error.

Approach to Tracking Problems

In the analysis of manual control systems, human operators have been considered "adaptive" elements. Their response to a given stimulus varies. Differences in response occur due to changes in situation and changes in operators. An operator's tracking performance or response is his composite of all of the system outputs with which he is presented. This is formulated into his output format which is aimed at performance optimization. The operator is guided in this accomplishment by the amount, type and form of information presented to him.

The task of tracking is considered a closed-loop manual control system since a portion of the output, the difference between response and the target, becomes input to help drive the operator to eliminate or at least moderate error. Tracking systems have been characterized by the type of input presented to the tracker. One class of tracking is called pursuit tracking. (Figure 2-1). This system presents the operator with both the target's path and the trackers response. These two signals are presented at the same time but are distinctly different. Thus these signals become two inputs. The tracker will attempt to modify his output pattern to reduce the error or the difference between these two signals. Another system is called compensatory tracking (Figure 2-2). Here, only a single input is presented to the tracker. This input is the error. The tracker reponds in a manner intended to reduce the error without having knowledge of the target or the tracking signal locations. The pursuit tracking system thus has a basic advantage. Senders and Cruzen, in 1952, suggested that performance was generally improved by using pursuit tracking.

An additional system is known as preview tracking (Figure 2-3). This system has also been called predictive tracking. Here, some knowledge of system response at a future time is presented to the tracker. A 25% reduction in tracking error through the use of preview tracking was demonstrated by Wierville in 1964. Preview tracking is present in more everyday tasks than any other tracking system. A common example would be riding a bicycle. The rider can see future changes in his path as he approaches them and controls his bicycle accordingly.

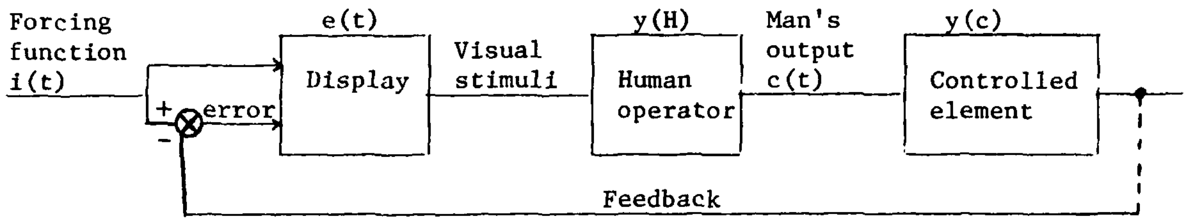


Figure 2-1. Pursuit Tracking

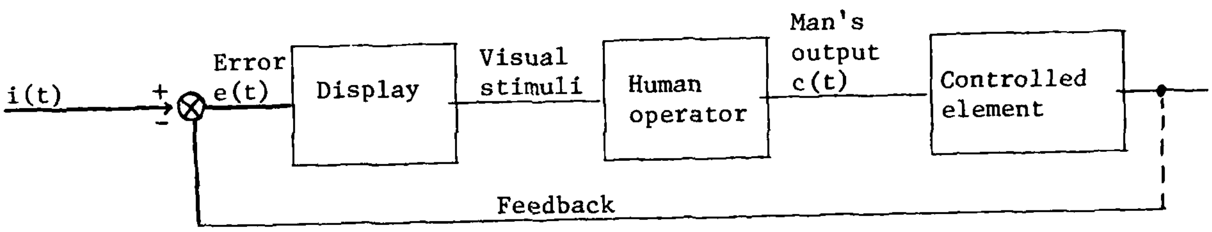
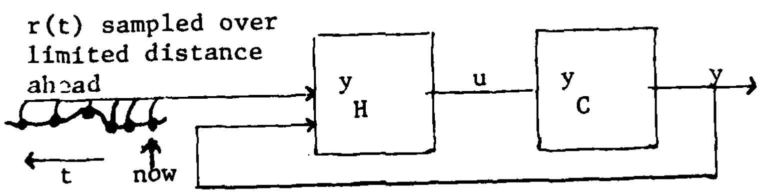


Figure 2-2. Compensatory Tracking



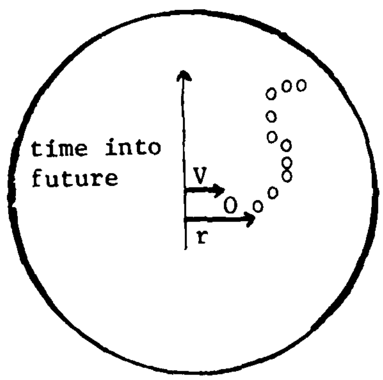


Figure 2-3. Preview Tracking

Classes of Variables

The properties of a particular situation are considered the variables that affect an operator's response in a manual control system. There are four broad classes of variables. Task variables are in the first class of variables. The operator works only in task related variables. This class of variables depend on the physical system being operated. Task variables include such things as input signals, the type of information displayed to the operator, the format of information display and the control device used by the operator.

The next class of variables includes the environmental variables. These factors are such things as vibration, visibility, temperature, wind load, illumination, additional tasks and other general working conditions. Environmental variables can be held constant in most cases for experiments run under laboratory conditions.

The third set of variables are called operator-centered variables. These variables are such intangible items as training, motivation, skill and both mental and physical fatigue.

The last class of variables includes the procedural variables. These variables are such factors as performance instructions, order of trials, measurement of performance and the resources of time and effort to be used.

Tracking Experiments

Tracking experiments have been run under laboratory and field conditions. Laboratory experiments typically involve operators attempting to track some type of target which has been projected on a CRT display. Field experiments typically measure performance under actual conditions with operators attempting to track using an operational system, such as a laser designator system equipped with the necessary data collection apparatus.

The elements of a laboratory experiment are a visual display, an operator, a control lever and a control element. The control lever transforms the operator's response signal to a machine signal. The control element sums the dynamics of the external elements and makes the appropriate correction which is then fed to the display. Early work of this nature used a spot driven by a random signal generator as the target. The tracker attempted to match a reference cursor on a CRT display to this target. The cursor was controlled by a hand control known as a joy stick. The effects of different variables could be measured by entering different parameters into the system. The effect of an uncooperative target was simulated by changing the pattern that the target negotiated.

Laboratory experiments normally utilize two classes of performance measures. One measure is time on target. Such a measure is used when targets are larger than point type targets and when discrete areas of targets are being analyzed. Since time on target scores have been found to be non-linear and relatively insensitive to small changes in human performance, this measure is not generally recommended.

The second performance measure is root mean square error. Typically an electrical device continuously measures the magnitude of error as an electrical voltage. This voltage is squared and integrated over time for the period of a trial run. Such voltage may be recorded on a printout or visually displayed on a voltmeter. The index of error is calculated from the square root of this voltage. To eliminate bias in the system, voltage is calculated with respect to an absolute reference of zero volts. Thus the RMS error gives the experimenter a measure of the tracker's variability in his distribution of amplitude and any constant error in his average cursor position

Field experiments are more realistic means of gathering tracking data but do not have as many controls as laboratory experiments to hold certain variables constant. Field experiments are generally used to accomplish performance testing on an operational or developmental system. An example is a laser designator where performance in tracking can be measured utilizing sensors on the target. The designator would be positioned as normally used and performance can then be measured.

During field experiments, performance is generally measured by the tracker's deviation from either a marked or perceived aimpoint. This deviation becomes the measure of error. It can be recorded continuously over the trial or at discrete points in time. System parameters and tracking performance derived from such data give more realistic evaluations than those resulting from a laboratory experiment.

Distribution of Error

Tracking error has been classically assumed to follow a bivariate normal distribution. Early notions of this nature were found in military firing tables. Hit probability of a tank gunner was based on a normal distribution of error. This assumption had considerable intuitive appeal but the first empirical study to substantiate its authenticity was not published until 1955 [Fitts, Bennett and Bahrick, 1955].

Fitts, Bennett and Bahrick presented their study at the 1955 Symposium on Air Force Human Engineering, Personnel and Training Research. They used autocorrelation and crosscorrelation analysis to study tracking error. The trackers were 50 male and 50 female subjects who tracked a 10 cpm sinusoidal motion of a line on a CRT display over 14 runs per subject. The target line remained stationary in the center of the display. The cursor could be moved to the right or to the left depending on the motion. A block diagram of the experiment is illustrated in Figure 2-4. This was a compensatory tracking task. Performance measures were RMS and time on target error scoring. Three zones of error corresponding to .1, .3, and .6 inches of displacement on either side of the cursor were considered. The RMS and time on target scores were plotted and compared to scores which were predicted under the assumption of normality (Figure 2-5). It was concluded that the empirical curves corresponded to the normality assumption.

These researchers also explored learning. They plotted error amplitude for the second, sixth, and fourteenth runs of the trackers. These distributions were compared against normal curves with the same mean and standard deviation as the test data. These results plotted together are shown in Figure 2-6. The researchers determined that the male subjects used in this experiment were better trackers than the females used. They took the error amplitude distribution of the males, converted their raw scores to standard normal scores and plotted

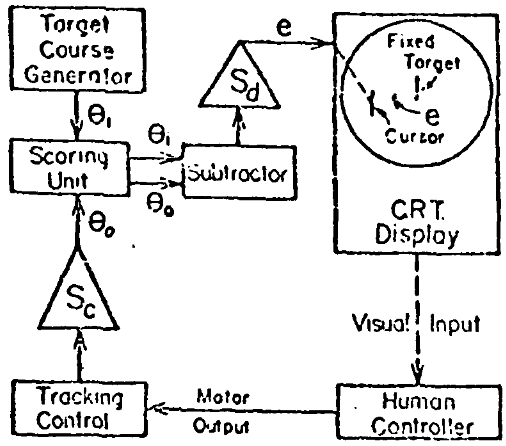


Figure 2-4. Block diagram of the OSU Electronic Pursuit Apparatus, adjusted to provide a compensatory display. (ref.[9], Fitts, Bennett, Bahrick)

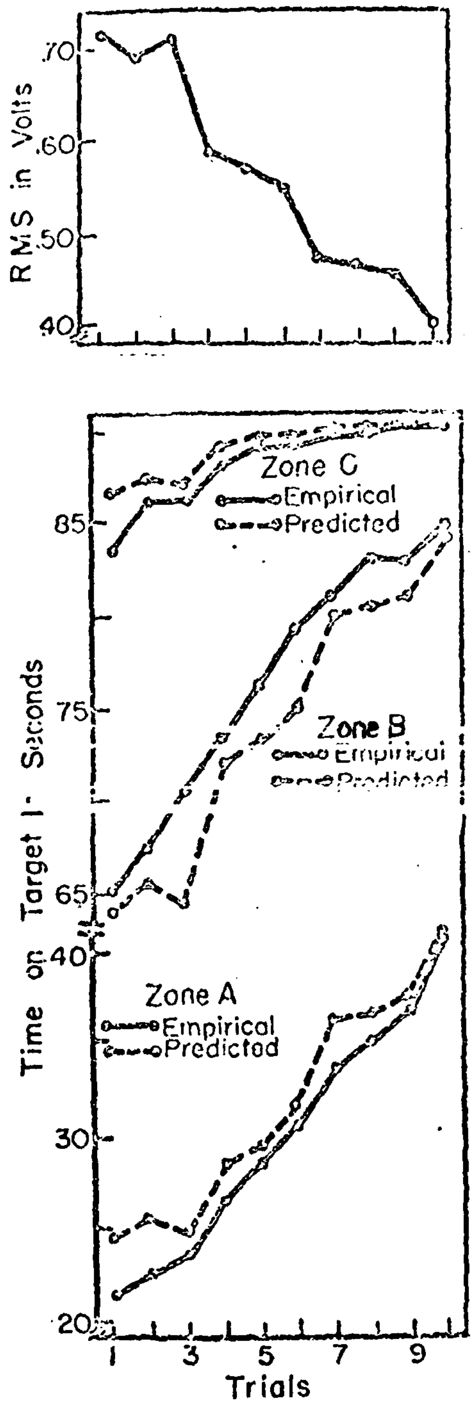


Figure 2-3. Time-on-Target and RMS Scores of 25 Male Ss on a Simple Tracking Task

this adjusted data against the corresponding normal curves (Figure 2-7). The conclusions were that "after some practice in tracking coherent targets, the error records of individual subjects tend to have a normal or nearby normal amplitude distribution. . . .The correlations among error RMS scores and various time on target scores follow a pattern that would be predicted on the assumption that all scores are samples from a process that has a normal amplitude distribution."[1]

The normality assumption was field tested in early 1977 under the auspices of the U.S. Army Human Engineering Laboratory (HEL). The Systems Performance and Concepts Directorate of HEL collected data on trained trackers in an attempt to substantiate the normality assumption. The operators used a laser designator. The targets were front and side views of a tank silhouette. The trials were made with and without a marked aimpoint. The ranges used were a .96 km and 2.01 km. The experimenters plotted a predicted distribution, using the assumption of normality and the actual cumulative probabilities, versus the tracking error. A calculator plotter at Aberdeen Proving Ground was used to accomplish this. A typical graph of their results is shown in Figure 2-8 (a), with the worst case shown in Figure 2-8 (b). The conclusion of HEL was that human tracking error, in trained trackers, followed a bivariate normal distribution.

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[1]Fitts, Bennett, Bahrick, p. 40.

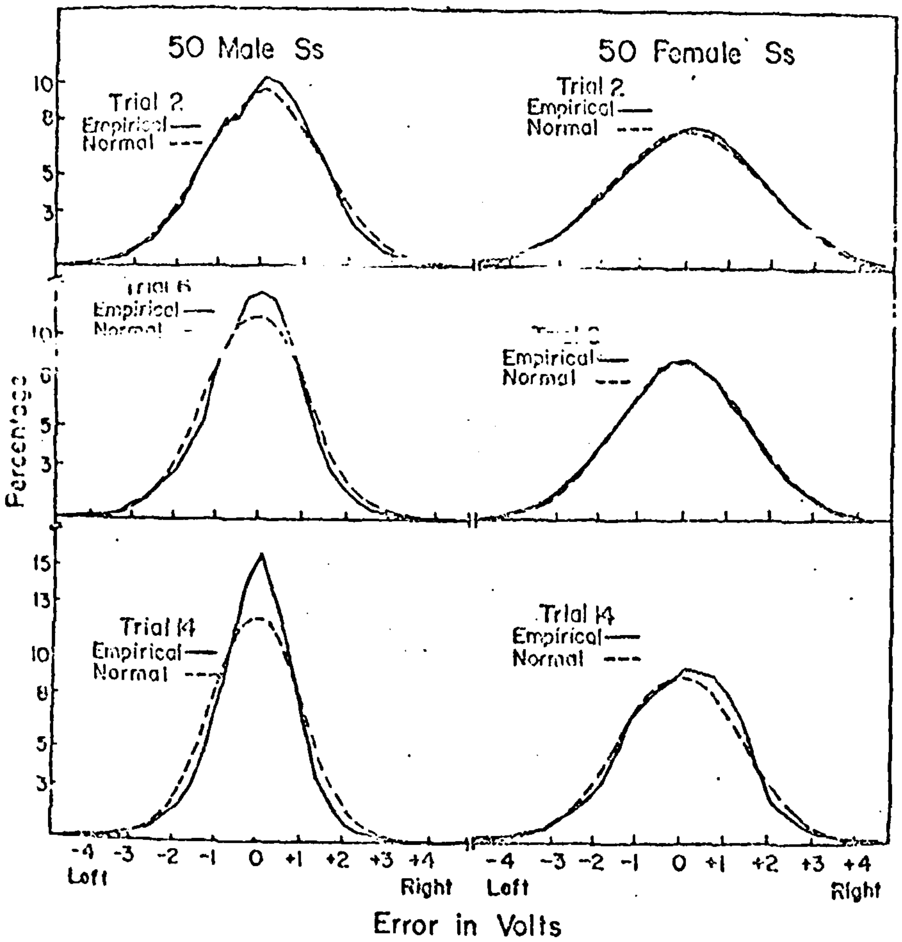


Figure 2-6. Empirical Distribution of Error Amplitudes at Three Stages of Training

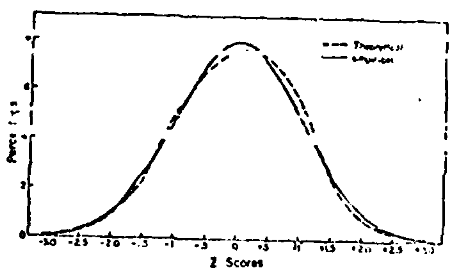


Figure 2-7. Error Amplitude Distribution for Male **Xx** on Trial 14, After Conversion into Z Scores

Human Error in Tracking

Performance in a tracking task is affected by various factors. Most of these are physiological. Physiological factors can affect individuals in different degrees.

Body tremor is a major source of physiological error. This may be defined as an involuntary trembling or shaking of voluntary muscles of the body or parts of the body. Environmental, emotional or physiological factors may be the cause of tremor. Tremor error is compounded with the small amount of mass inertia found in almost every type of control mechanism.

A viscous damped resistence system is composed of one or more rotating members, a rotor and one or more stationary numbers, a stator. A fluid of high viscosity and resistance to shear lies between these members. The incorporation of a viscous-damped resistance system into the control loop of an optical control task can moderate tremor and allow the physical movement of the control mechanism to be smooth. This resistance system has several operational characteristics which aid in the accomplishment of smooth physical movement. It eliminates tremor because it resists any quick movement. It reduces the chance of undesired activation and helps the tracker make smooth controlled movements. The resistance to shear in this system is directly proportional with the control velocity placed on the control, but is independent of acceleration and displacement.

Another source of error not inherent in the tracking task is the movement and fixations of the eye. The eye samples at an extremely high rate of speed as opposed to continuously monitoring an object.

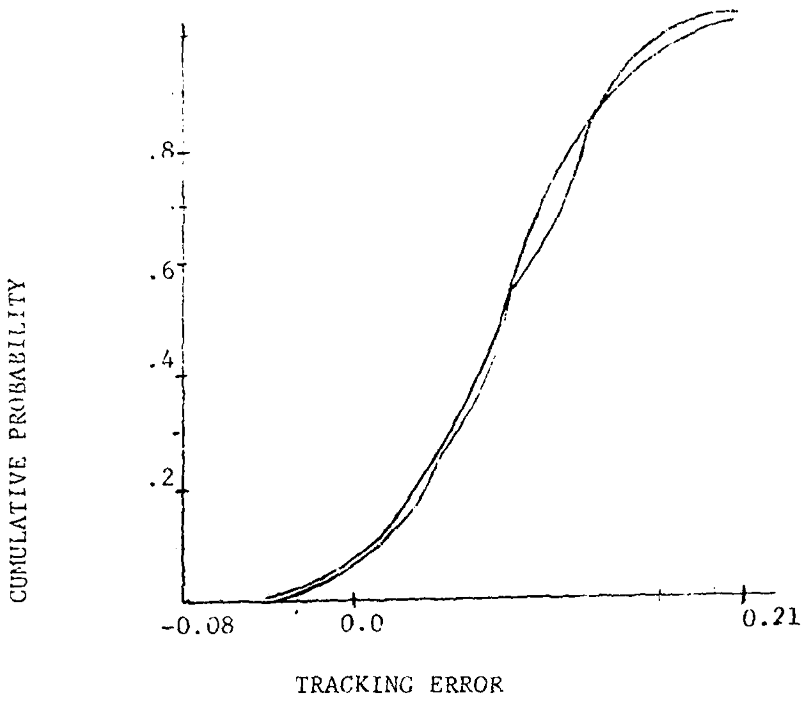


Figure 2-8(a). Typical error distribution, HEL Field Test, 1977.

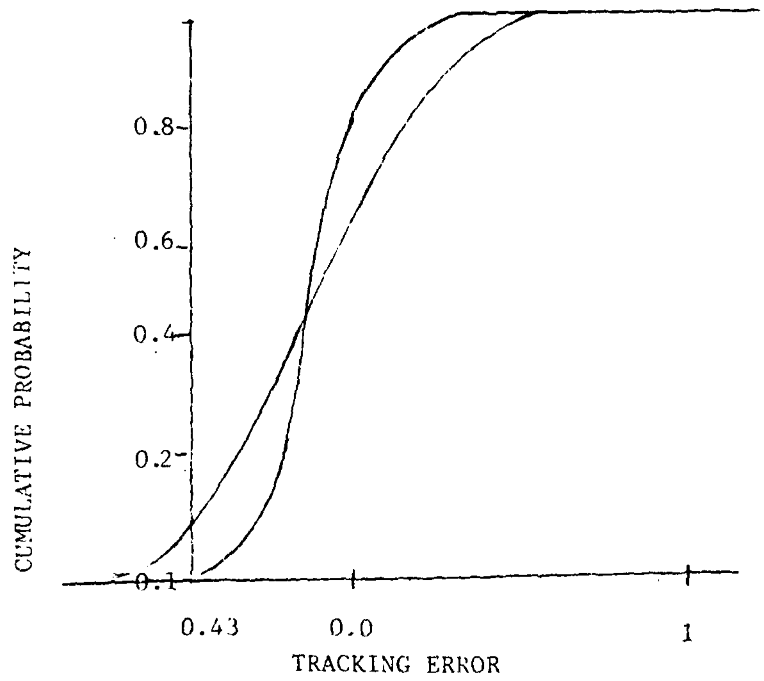
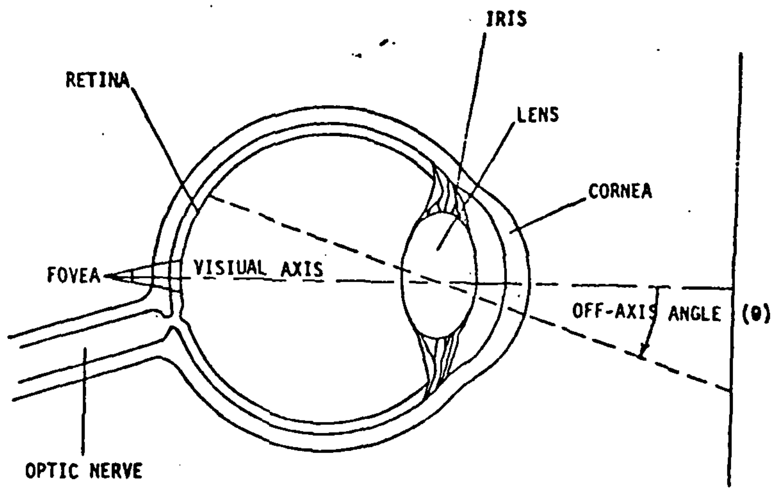


Figure 2-8(b). Worst Error Distribution, HEL Field Test, 1977.

In taking these samples, the eye is capable of making many discrete movements each second. Three readily distinguishable types of eye movements were reported by Ratliff and Riggs in 1950. These were: (1) high frequency tremor of 30 to 70 cps with low amplitude of 15 to 20 seconds of arc; (2) slow drifts lasting up to 10 seconds with amplitude up to five minutes of arc: and (3) saccades or very rapid flicks occuring at irregular intervals with a mean of six minutes of arc. In 1956, Cornsweet demonstrated that in subjects with normal, healthy eyes the first two types of eye movement have no effect on stability of the visual world and cannot be controlled. Individuals can, however, exercise visual control over saccadic motion which serves to realign the eye on its fixation point.

A schematic drawing of the eye (Figure 2-9) aids in the understanding of this concept. A line drawn through the center of the lens and retina is the visual axis. The off axis angle is labelled and is one half the visual angle. The visual angle is the angle subtended by the eye to encompass an object. Visual information is initially processed by the retina and transmitted to the brain by the optic nerve.

Saccadic movement of the eye occurs one to ten times per second. The eye fixates on individual areas between the saccades. This time period is known as a glimpse rate. Only a small area around the point of fixation is clear to the eye necessitating movement of the eye. The fovea, located in the center of the retina, is the only portion of the eye which has receptor cells packed closely enough together to make clear resolution possible. Thus, the area around the fixation point will be hazy. In order for the brain to receive a clear image, it is therefore



GEOMETRY OF EYE

Figure 2-9. Effects of Visual Acuity on Target *Acquisition* (ref. [13], Laskin) necessary for the eye to move.

The effects of eye movements on tracking, visual acuity and recognition have been researched intensely. The importance of the relationship of eye movemetns and visual tracking is debated by various authors. For the purpose of this research, saccadic movement will be treated negligible based on several facts. After recognition, visual perception of the target is directly comparable to looking at a picture. Short term memory and awareness of surroundings project the entire target clearly to the brain, even though much of the target might lie in the hazy peripheral vision ranges.[2] Movement of the eye during tracking is at a minimum and saccades should average only approximately one per second.

Another source of error inherent with the eye might be the blink rate. In 1948, Lawson demonstrated that there is no degradation in tracking performance after a blink, intentional or unintentional. This has been supported by others. It has also been demonstrated that the blink rate is reduced from 18 per minute at rest to as few as three per minute. This is dependent upon target resolution difficulty.

Another factor affecting error in tracking tasks has been termed the range effect. This is a tendency to overshoot small inputs and undershoot large inputs.

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[2]Speech by J.D. Gould, "Looking at Pictures," Eye Movement and Psychological Processes, edited by Richard A. Menty and John W. Senders. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1976, p. 333.

Other variables which can contribute to non-tracking human error are stress, fatigue and accuracy vs. time. There is no good analytic technique for predicting the effect of each of these items on the tracking task. Specific tables have been developed for certain asks. No general data is available. Because of the wide ranges of human behavior and precise system characteristics, these factors can only be properly analyzed by experimentation or simulation.

Learning

Learning was considered improvement in psychomotor skills and mental perception to reduce or moderate error. Quick initial learning has been found to occur when a subject utilizes physical movement in response to stimilus. Best retention has been found to occur when the subject uses trial and error to modify his response to supply a correct output pattern.

In tracking tasks, learning can be considered to occur when a tracker's performance reflects a consistent decrease in deviation, in mean error, in range of errors or in standard deviation of errors. Fitts, Bennett and Bahrick also showed that the distribution of errors changes over time. Such changes as spiking of the distribution can be an indication of learning.

Bahrick, Fitts and Briggs dealt with learning curves in a 1957 article which supported their earlier work. They used the same data and tried to explain why deviations from normal were obtained in the experimental work. In this article, the conclusion was that "the peaking is not due to departures from normality distributions which among themselves are not normally distributed."[3] The researchers again concluded that the normality assumption held for trained trackers, but this was conjectured not substantiated.

Classical work suggested that repetition aided in the improvement of performance. Much of this work involved industrial learning and concerned studies to decrease the time needed to perform certain tasks. Plots of these decreasing time scores vs. successive trial number provided the classical concept of a learning curve. Such curves have been modeled using many mathematical equations. Common equations which fit learning curves are $\hat{y} = at^{-b}$, $\hat{y} = ae^{bx}$, and $\hat{y} = ae^{b/x}$. Curves have not been fit during training.

Poulton divides repetition into three phases. The first phase is pre-training where the subject gets familiar with the equipment. Training is the second phase in which decrease in error or improvement in performance. The final phase is transfer, which assumes a fully learned subject now can use his skill on similar systems.

In many studies mean error is used as the performance measure. This suggest that subjects make smaller errors as they learn. In tracking mean error as a performance may be masked by a subject's increasing tendency to overshoot, to lead or to swing through a target. Thus a measure of performance that accurately describes learning must be evaluated for specific types of tasks. There is no linear relationship between measures. Each must be examined independently.

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[3]"Learning Curves, Arts or Artifacts." Psychological Bulletin, Vol. 54, No. 3, 1957, p. 263.

CHAPTER III

EQUIPMENT AND EXPERIMENTAL PROCEDURES

The equipment that was used in this experiment was an apparatus developed by the U. S. Army Human Engineering Laboratory (HEL) at Aberdeen Proving Ground, Maryland. This piece of equipment consisted of a movie camera, lens, rifle scope and tripod. These parts were mounted together as one unit, thus enabling experimenters to make a photographic record to be used in analyzing an operator's ability to track.

The rifle scope was mounted to the top of the movie camera by means of a slide bracket. The scope had a sight extension and a collapsable rubber cuff on the rear to enable the operator to get a good sight picture. The scope had a crosshair for the operator to use in an effort to track the moving target. The rifle scope had a variable power of 2.5x to 8x.

The movie camera was equipped with a six-inch lens and filmed the moving target at four frames per second. The camera was a Milliken movie camera. It used 16 millimeter color movie film. The internal mechanism had a retractable claw which protruded through the doubly perforated film as each frame was positioned in front of the shutter. This eliminated slippage and gave a firm picture of the tracking effort.

The camera was affixed to a general purpose viscous damped tripod which had been developed by HEL. The tripod with its traversing unit weighed approximately 12 pounds. It was designed to be used with loads in the range of 5 to 32 pounds. Such loads typically may be lightweight missile launchers or a variety of optical devices. The eye height relative to ground level may be 22 to 26 inches, depending upon the device affixed to the tripod. In this experiment eye height was adjusted to the individual's position. The traversing unit encompassed a two-fold damping system. In the elevation axis the damping system was a drum type system. The assembled apparatus is shown in Figure 3-1.

The operator assumed a sitting position to the rear of the apparatus (Figure 3-2). Preprinted instructions were given to the tracker (Appendix B). The mount was traversed utilizing hand grips mounted in vertical positions on either side of the traversing unit and applying a torque in order to track a target. Torque may be applied in both the elevation and azimuth axes. System damping characteristics are given in Appendix A.

The movie camera required 24 volts of direct current for power. Power was supplied by two motorcycle batteries. A power cable had been provided by HEL. An off-on switch was included on the cable and was operated without undue distraction. The use of motorcycle batteries allowed the apparatus to be easily transported and enabled the experiment to be conducted in a field location.

The experiment was conducted in an open area. The operators may have been exposed to wind loads. The trials were conducted during daylight. The same amount of sunlight was present in all trials. There were no obstructions in the line of sight between tracker and target. The operator rested between trials so as not to interject fatigue into the

Figure 3-1. Tracking Station Assembly

Figure 3-2. Subject and Controller at Tracking Station

experiment. The operators were instructed in techniques to stabilize their body position and body position was consistent in all trials. The operator could only sight using one eye and the head was held firmly against the sight extension in order to reduce paralax error. Again, consistency in head position was maintained throughout the trials.

Four subjects were monitored. All were naive trackers. Prior to the initiation of each trial the subject laid the rifle scope cross-hairs on a marked aimpoint. The aimpoint was a white cross on a black circle which was one meter in diameter. The circle was mounted on a white background as shown in Figure 3-3. The scope power as 5x which presented a visual angle of 85.95 minutes of arc. The crosshairs of the sight were left on the aimpoint for 5 seconds to establish a reference aimpoint and remove any paralax error between the scope and the camera. The system was then considered boresighted.

The target then initiated movement at a constant speed of five m.p.h. and maintained that speed for 15 seconds. The camera, operating at a speed of four frames per second, monitored the tracking of film was not analyzed since error due to acceleration was not the subject of this study. Each subject replicated 60 trials of this same procedure.

The 60 trials per subject were analyzed in the following manner. The first 10 trials of each subject were filmed and analyzed completely. Between trials 11 and 20, every other trial was analyzed. From 21 through 40, every fifth trial was measured and the 50th and 60th trials were filmed to complete the analytic process. The use of these last two points were a check against reaching a plateau in learning instead of an asymptote at the fully learned stage. Each subject then had a learning curve, standard deviation of error vs. trial number, plotted based on 21 data points.

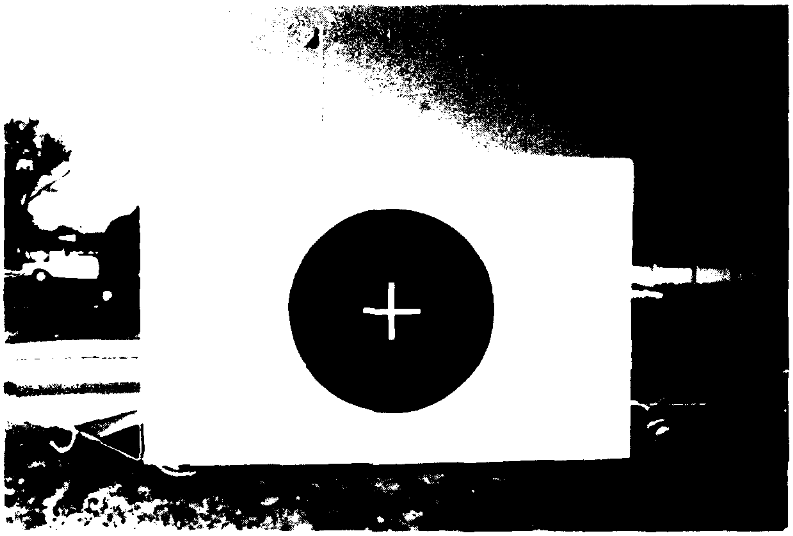


Figure 3-3. Target (with marked center used for zero)

CHAPTER IV

DATA ANALYSIS PROCEDURES

The end result of experimentation was four rolls of movie film. This film was taken to the Human Engineering Laboratory at Aberdeen Proving Ground, Maryland for initial data reduction. The film was projected onto the rear of a screen. The front of the screen was equipped with a movable cursor which displayed deviations from the marked target center as digitized numbers accurate to 0.01 inches in the azimuth (X direction) and elevation (Y direction). Upon activation, the digitizer recorded these deviations on a printout and in computer punch tape form. The film was advanced one frame at a time. For each trial 53 frames were analyzed to be used as data points. These points were chosen close to the middle of each run to avoid errors caused by acceleration or by fatigue. A new zero point was obtained for each run by utilizing the tear strip of frames of the stationary target. In examining the errors between zero points of the analyzed trials, the average deviation was 0.1 inches in both directions on the target board. This value was overshadowed by later values of standard deviation of tracking error which range from 1.5 to 11.4 inches. A computer plot routine utilized values from the punch tapes to plot X and Y deviations vs. successive frame number for each trial.

The resulting computer punch tapes were brought back to Georgia Tech and entered into the Cyber 74 computer. The data points were then sorted by trial and subject. The errors were converted from inches of deviation measured by the digitizor cursor into inches of deviation on the actual target. Utilizing the plots of successive deviations and the printouts of errors, outliers were discarded. Outliers were those points whose large deviation were not considered representative of the subjects true tracking performance and whose values were significantly different from the values found elsewhere in that trial. Both negative and positive outliers were discarded. Ten trials of the 85 analyzed had no outliers. One subject had three extremely deviant trials. It was decided that for three runs, points more than 20 inches from the aimpoint should be discarded since this study dealt with tracking performance on a target which was one meter in diameter.

The data was further reduced using two computer programs. The first program printed a histogram of frequency of errors. The minimum and maximum values of the errors were established. This range was then divided into seven equal intervals with a printout showing how many of the data points fell into each interval. The program also calculated the mean and standard deviation for each data set.

The second program computed statistics for each data set. For both the X and Y directions, this program computed the mean and standard deviation on each data set. It also incorporated a calculation of autocorrelations. Several test runs were made in order to determine the correct autoregressive process for the experimental data. Lag coefficients or correlating coefficients were calculated for Lag 1(t x t-1) through Lag 3 (t x t-3). The samples demonstrated an exponential decay (Appendix E). Discovery of this fact led to the adoption of the first order autoregressive process (AR(1)). Utilizing the Lag 1 coefficient, it was found that the deviation for one frame affected the deviation of the following. This was heuristically appealling since trackers typically make up to 3 corrections per second and the camera ran at 4 frames per second or close to one correction per frame. Incorporating this knowledge, the program calculated the adjusted standard deviation of error and the least squares estimators of the autocorrelation factors. Further discussion of the autocorrelation model can be found in Appendix F.

The histograms that resulted from the first program were of three general forms. These forms had shapes characteristic of uniform, normal and spiked normal distributions. The shape of the distributions changed over time but the changes were a function of the individual tracker and did not fit a general form. The distributions were more spiked in the Y direction.

The histograms listed the minimum and maximum values of each data set which gave the magnitude of the range of sample deviations or tracking errors. In the X direction the early value of range of error went up to 18 inches and declined to about 8 inches. In the Y direction ranges varied bewteen 10 and 6 inches with only a slight decline over time.

The histogram program was run on data sets which combined points for trial 30, 35, 40 and 60 for each subject. The histograms which resulted from these combined data sets produced plots characteristic spiked normal or normal distributions. Again, both plots in the X and Y directions varied among individual trackers.

CHAPTER V

EXPERIMENTAL RESULTS AND CONCLUSIONS

Results

Several measures were computed and examined for indications of learning. The values of the particular measures were averaged across all four subjects to give a single value for each trial analyzed. The averaged measure was then plotted vs. successive trial number in order to examine the effects of repetition of the statistic consideration.

Reversals were calculated from the plots of error vs. frame number. A reversal was considered to have ocurred when a tracker decreased the magnitude of his positive valued error, that is when he stopped increasing his error and began to track closer to the center of the target. These reversals were reflected as peaks on the plots of error vs. frame number. In both the X and Y directions no trend over time was evident when the average number of tracking reversals was plotted vs. trial number (Figures D-1, D-2).

Utilizing the plots of error vs. frame number, it was also possible to note the number of times the trace crossed the center line. This represented number of times the tracker changed from leading to lagging behind the center of the target or from undershooting to overshooting the center of the target. There were no clear trends over time noted when these numbers of times the centerline was crossed were averaged and plotted vs. trial number (Figure D-3, D-4). The number of crossovers in the Y direction was less than half the number of crossovers in the X direction.

This statistic can be misleading since trackers consistently overshot the aimpoint or swung through the target, shooting low during early frames and shooting high during the last frames. Subjects who overshoot constantly at 0.1 inches or 20 feet have the same value for crossovers.

The histogram program printed the maximum and minimum values of error in the X and Y directions. This information allowed the range of error to be calculated. The range of X errors was initially much greater than that of the Y errors, but the ranges became of more similar magnitude in later trials; 8 inches range for the X direction and 7 inches in the Y direction. A decrease over time was noted in both the X and Y directions when range was plotted vs. trial number (Figures D-5, D-6).

The mean errors of each subject for a given run were averaged across subjects to provide a measure referenced as average error in inches. This measure was plotted vs. trial number in Figures D-7, D-8. The average error in the Y direction fluctuated around 2.5 inches indicating a tendency of trackers to consistently overshoot the center of the target. Only a very slight decrease was apparent over time. The average error in the X direction fluctuated around 0.66 inches, indicating a slight tendency to lead the target center, although at times the subjects did in fact lag behind the center. There was a slight tendency to increase the lead over time. The spread of values of these averaged errors was approximately 1.8 inches in both the X and Y directions.

In using the autocorrelation computer program, the adjusted mean was calculated. This has been plotted as adjusted error in inches vs. trial number (Figures D-9, D-10). This statistic acknowledges that mean error is related to the subjects perception of the center point.

Here the spread of these adjusted values was approximately 1 inch in both X and Y directions. The adjusted values fluctuated about 0.43 inches in the X direction and 0.91 inches in the Y direction again showing the tendency for trackers to lead and overshoot a perceived or adjusted center of the target. The same slight tendencies over time were evident in the plots of the adjusted data as in the plots of unadjusted data.

The average autocorrelation factors at Lag 1 were plotted vs. trial number (Figure D-11, D-12). Both plots of the X and Y autocorrelations show a tendency to increase over time. Values in the X direction ranged from .25 to .55. In the Y direction, values spread from .58 to .82 indicating that errors in the vertical direction at time t are highly correlated to those at time t-1. This supports the previous contention that corrections were made based on the tracker's perception of his previous deviation.

The standard deviation of error averaged across subject in the Y direction showed a slight decrease over time (Figure D-13). The magnitude of standard deviations in the Y direction were comparable to the magnitude of those in the X direction at the end of training. The unadjusted values of standard deviation in the Y direction decreased over time from 2.2 to 1.6 inches. Each subject's standard deviation was adjusted for autocorrelation. These adjusted values averaged across individuals decreased from 1.6 to 1.3 inches (Figure D-14).

The most apparent display of learning was present in the plot of standard deviation of error in the X direction vs. trial number. The average X standard deviation values decreased from 3.9 to 2.1 inches (Figure D-15). The values adjusted for autocorrelation and averaged across individuals decreased from 3.6 to 1.94 inches (Figure D-16). This reflected the influence of autocorrelation. Similar patterns were evident in the plots of adjusted and unadjusted X standard deviation of error vs. trial number for each individual tracker (Figures D-17 through D-24). In all of these plots the majority of the decrease or learning takes place by trial number 10. The plot of standard deviation of error averaged across subjects shows that 82% of apparent learning occurred by trial number 10. In the case of two subjects, learning stabilized by trial number 5. The unadjusted X standard deviation for the combined data sets (Trials 30, 35, 40, 60) were 2.10, 2.20, 1.98 and 3.35 inches. The adjusted values became 1.8, 1.9, 1.5 and 2.7 inches respectively. At the end of training the worst early performance based on X standard deviation of error. The relative ranking of subjects based on this measure of performance is shown in Table 5-1. The best is one and the worst is four.

Table 5-1. Relative Ranking of Tracking Performance

Subject	Early Ranking	Final Ranking
J	1	3
D	2	1
C	3	2
R	4	4

It should be noted that the three best trackers had X standard deviations at the end of training which are very close in magnitude. This is examined by utilizing Bartlett's test to calculate the sample variance and necessary parameters for these trackers.

$S_1^{\,2} = (2.1)^2$ $\qquad$ $S_2^{\,2} = (2.2)^2$ $\qquad$ $S_3^{\,2} = (1.98)^2$

a = 3 = number of samples

N = 12 = number of cells

$$S_p^{\,2} = \frac{3(4.41) + 3(4.84) + 3(3.9204)}{12 - 3} = 4.39$$

$$q = (12 - 3) \log (4.39) - 3(\log 4.41 + \log 4.84 + \log 3.9204)$$

$$= 0.143$$

$$C = 1 + \frac{1}{3(2)} \qquad \frac{3}{3} - \frac{1}{9}$$

$$= 1.148$$

$$X_0^{\,2} = 2.3026 \ \frac{q}{c} \ = .2868$$

Since $X_0^{\,2}.05,3 = 7.81$, we may conclude that the variances of the three best trackers are homogenous. Their pooled unadjusted standard deviation is 2.10 inches. Thus their ranking at the end of training is more subjective than objective.

Utilizing a computer program for non-linear regression, curves were fit to two sets of data. Standard deviation of error in the X direction and standard deviation of error adjusted for autocorrelation in the X direction were fitted because they seemed to most accurately demonstrate learning over time. Three models were chosen as candidates. These models were $y = at^{-b}$, $y = ae^{b/x}$, and $y = ae^{bx}$. The results of curve fitting are tabulated in Table 5-2. Based on minimizing the sum of squares of residuals, the model $y = at^{-b}$ fits best for both data sets. The fitted curves are shown in Figures D-25, D-26. Curves were also fit to data sets of the adjusted and unadjusted standard deviation of error for trials 9 through 60. All curves had low or favorable lack of fit ratios. Lack of fit ratio is defined as $\frac{\text{Mean Square Error (Lack of fit)}}{\text{Mean Square Error (Pure Error)}}$. Mean Square Error (Pure Error) = $\frac{\text{Sum of Squares (Pure Error)}}{\text{Degrees of Freedom}}$. Mean Square Error (Lack of fit) = $\frac{\text{Sum of Squares (Lack of fit)}}{\text{No. of obs. } -2}$.

Table 5-2. Curve Fitting of Residuals

Data Set	Model	Sum of Squares of Residuals	Parameter Values		Lack of Fit Ratio
Standard Deviation in X	$y = at^{-b}$	171.2361	a=4.0187	b= 0.1537	.4737
Standard Deviation in X	$y = ae^{b/x}$	178.6409	a=2.5743	b= 0.4926	.6304
Standard Deviation in X	$y = ae^{bx}$	176.3054	a=3.3359	b=-0.0104	.5810
Adjusted Standard Deviation in X	$y = at^{-b}$	87.3311	a=3.7088	b= 0.1759	.2734
Adjusted Standard Deviation in X	$y = ae^{b/x}$	93.0665	a=2.2229	b= 0.5837	.4983
Adjusted Standard Deviation in X	$y = ae^{bx}$	93.8284	a=2.9795	b=-0.0115	.5281
Standard Deviation in X 9-60	$y = at^{-b}$	32.0308	a=2.4790	b= 0.0143	.3306
Standard Deviation in X 9-60	$y = ae^{b/x}$	32.0524	a=2.3719	b= 0	.3330
Standard Deviation in X 9-60	$y = ae^{bx}$	31.9770	a=2.4369	b=-0.0010	.3246
Adjusted Standard Deviation in X 9-60	$y = at^{-b}$	16.9378	a=2.4442	b= 0.0513	.1865
Adjusted Standard Deviation in X 9-60	$y = ae^{b/x}$	16.9797	a=1.9875	b=-0.9013	.1950
Adjusted Standard Deviation in X 9-60	$y = ae^{bx}$	16.9534	a=2.1931	b=-0.0019	.1897

CONCLUSIONS

The two objectives of this study were to investigate learning in subjects doing a tracking task and to investigate measures of performance to find the measure which most accurately describes learning. Based on the plots of performance measure, standard deviation in the X direction is the best measure of learning in this tracking task. The learning appears to be occurring in the first ten trials. These trackers appear to level off at a fully trained status after trial number 10, ending with an unadjusted standard deviation of 2.10 inches or an adjusted standard deviation of 1.94 inches. Substantial autocorrelation is present requiring the use of a lag 1 model to correct the data to an uncorrelated form. By the end of training all subjects were able to track the aim-point within the edges of the target. These trackers tended to overshoot or swing through the target in the elevation plane and tended to lead the target. Histograms of the frequency distribution of errors showed no trends of changing shape over time. Changes were a function of individual tracker rather than a general form of change.

In attempting to fit curves of the data of standard deviation in the direction and standard deviation of error adjusted for autocorrelation in the X direction, the best model was $y = at^{-b}$ in both cases. The models which fit were $y = 4.1087t^{-0.1537}$ for standard deviation of error and $y = 3.7088t^{-0.1759}$ for adjusted standard deviation of error.

Recommendations

Due to outliers in the data set, analysis was done on less than

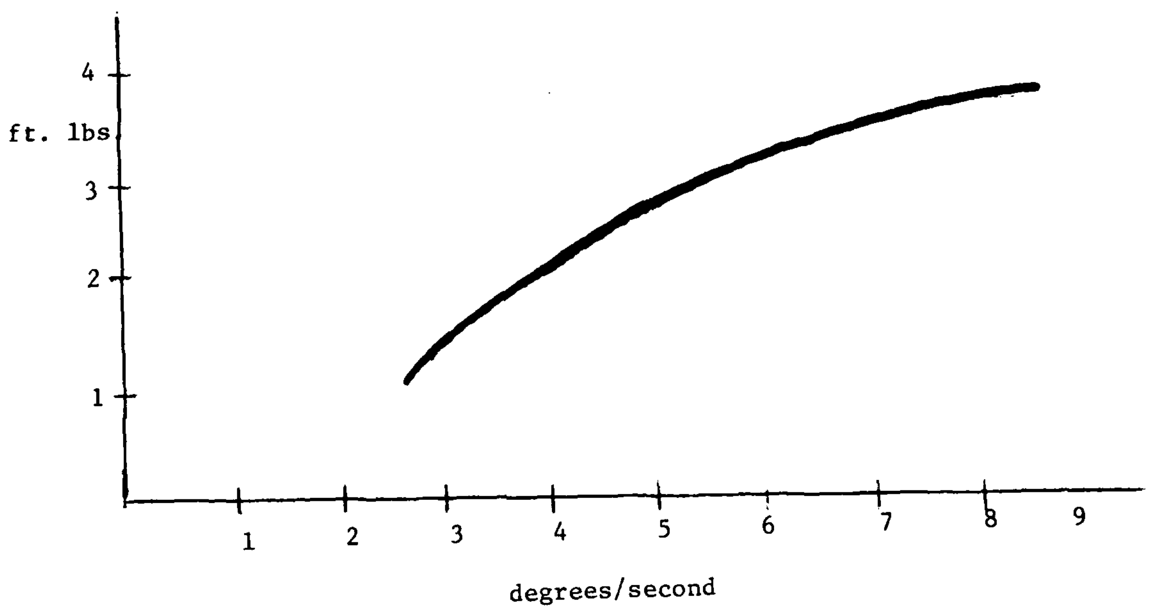
50 points. More points for use in statistical reduction would give a more precise description of error. It is recommended that 100 points be collected for each data set in future experiments of this nature. It is further recommended that more subjects be used as trackers for future studies. They should be chosen on a demographic basis.

In this study, the major portion of learning occurred in the first ten trials based on standard deviation of error in the X direction. It is recommended that this statistic be used as the performance measure in future experiments. In the course of future experiments autocorrelation should be considered to correct tracking results.

Since the tripod examined in this experiment is not in wide field use, it is recommended that experiments similar to this be conducted on U. S. Army equipment such as the Tube Launched, Optically Tracked Wire Guided Missile and The Dragon Missile System. Using the results of these future experiments, trainers can revise their estimate of the number of runs needed to fully train operators or can estimate the point at which trainees should be tested for qualification in a more economical fashion.

Recommendations for further experimentation include the effects of noise, smoke, fatigue or intervisibility on tracking performance. Other experiments could measure the effect of target shape, contrast or cooperation on tracking performance. A factorial experiment can combine several of test factors and test interaction at the same time. The goals of such future work should be performance modeling and better training devices.

APPENDIX A



Tripod Damping Characteristics
Horizontal Plane

APPENDIX B

APPENDIX B

Subject Instructions

1. Assume a comfortable and stable sitting position.
2. Relax.
3. Keep your eye in relatively the same position over the eye piece.
4. Attempt to keep the cross hairs in the center of the target.
5. As the target moves, establish a tracking rate by applying smooth horizontal and vertical corrections to the handle on the traversing unit.
6. Breathe normally while tracking.
7. Attempt to track the center of mass of the target at all times. The white cross hair on the target will point it out.

APPENDIX C

C-1. X Reversals

TRIAL	CON	DENNIS	JOHN	RANDY	AVG
1	12	13	11	14	12.5
2	13	13	14	12	13
3	11	10	13	11	11.25
4	16	13	13	12	13.5
5	14	12	8	7	10.25
6	12	9	9	11	10.25
7	14	12	11	7	11
8	14	10	12	12	12
9	12	11	11	10	11
10	13	12	10	15	12.5
12	14	11	11	14	12.5
14	13	9	12	11	11.25
16	12	12	12	13	12.25
18	11	12	11	11	11.25
20	13	14	13	8	12
25	14	9	10	11	11
30	11	11	10	11	10.75
35	10	12	10	11	10.75
40	12	10	13	13	12
45	--	10	--	12	11
50	11	11	--	11	11
60	11	14	12	14	12.75

C-2. Y Reversals

TRIAL	CON	DENNIS	JOHN	RANDY	AVG
1	12	13	14	9	12
2	10	13	16	11	12.5
3	14	11	12	12	12.25
4	11	13	10	12	11.5
5	15	10	11	9	11.25
6	14	12	9	10	11.25
7	13	14	12	11	12.5
8	12	11	11	12	11.5
9	17	12	19	12	12.5
10	13	12	11	12	12
12	11	11	8	10	10
14	14	13	10	14	12.75
16	11	11	8	12	10.5
18	13	11	9	13	11.5
20	12	10	10	8	10
25	16	13	7	13	12.25
30	11	10	11	10	10.5
35	14	12	12	14	13
40	14	11	13	10	12
45	--	12	--	9	10.5
50	11	9	--	10	10
60	15	9	14	9	11.75

C-3. X Crossovers

TRIAL	CON	DENNIS	JOHN	RANDY	AVG
1	13	14	15	25	16.75
2	15	9	13	19	14
3	14	6	17	18	13.75
4	17	13	9	19	14.5
5	17	14	10	13	13.5
6	18	14	12	9	13.25
7	12	10	13	4	9.75
8	15	12	15	19	15.25
9	17	16	11	15	14.75
10	18	16	14	22	17.5
12	17	13	5	15	12.5
14	20	14	19	17	17.5
16	17	8	12	15	13
18	10	13	11	20	13.5
20	15	8	9	11	10.75
25	21	13	6	15	13.75
30	15	11	18	12	14
35	17	2	10	9	9.5
40	9	8	8	9	8.5
45	--	10	--	10	10
50	11	6	--	14	10.33
60	12	8	13	13	11.5

C-4. Y Crossovers

TRIAL	CON	DENNIS	JOHN	RANDY	AVG
1	3	5	7	7	5.5
2	9	0	9	7	6.25
3	7	2	11	2	5.5
4	7	0	5	2	4.875
5	5	0	0	0	1.25
6	5	0	5	2	3
7	15	2	5	4	6.5
8	3	0	1	0	1.0
9	13	0	6	2	5.25
10	6	0	5	2	3.25
12	6	0	3	2	2.75
14	9	0	10	3	5.5
16	7	0	5	0	4
18	7	2	5	0	4.5
20	10	0	6	4	5
25	11	0	5	4	5
30	6	2	4	0	3
35	1	4	1	0	1.5
40	0	0	1	4	1.25
45	--	0	--	0	0
50	1	4	--	5	3.33
60	11	2	8	2	5.75

C-5. X Error Range

TRIAL	JOHN	RANDY	DENNIS	CON	AVG
1	10.66667	22.85711	11.80953	16.7619	15.523802
2	10.66667	24.381	10.66667	12.52381	14.809537
3	8.7619	20.19046	11.80953	12.952381	13.28567
4	8	18.2857	11.37144	9.90476	11.890476
5	8.38095	30.8572	8	6.85714	13.523822
6	6.47619	23.23809	11.80953	9.52381	12.761905
7	8	40.381	12.19048	11.04762	17.904775
8	9.52381	14.85715	11.42857	10.66667	11.61905
9	6.47619	10.66667	9.14286	8	8.57143
10	7.61905	12.19047	7.61904	8.7619	9.047615
12	7.61905	11.80952	10.28571	8.76191	9.619045
14	9.90476	10.28572	9.14286	9.52381	9.7142875
16	7.61905	11.88952	8	6.47619	8.49619
18	8.76191	10.66667	8	8.76191	9.0451225
20	6.85714	22.9048	8	6.85714	13.90477
25	8.38095	9.90476	10.28571	10.28571	9.7142825
30	8	11.04762	6.85716	8.7619	8.66667
35	6.85714	13.33333	6.47619	6.85714	8.38095
40	8.38095	9.90476	6.85716	9.14285	8.57143
45	-------	9.90476	6.85714	-------	8.38095
50	-------	12.57143	6.85714	8	9.148566
60	7.61905	8.76191	7.61904	8.38095	8.0952375

C-6. Y Error Range

TRIAL	JOHN	RANDY	DENNIS	CON	AVG
1	6.85714	14.09522	7.2381	9.14286	9.33333
2	6.47619	14.85718	6.85714	15.2381	10.857152
3	6.47619	9.523805	13.71427	9.52381	9.8095187
4	8	10.66666	8.761908	8	8.8571195
5	5.333338	16.76189	8	7.23809	9.3333275
6	6.09524	20.571405	10.666695	9.14286	11.61905
7	6.85716	17.142848	11.80951	6.85714	10.666664
8	6.09524	10.28574	10.6667	7.2381	8.571445
9	5.71428	9.904765	9.52379	7.61904	8.1904687
10	8.38096	14.476205	9.90476	7.23809	10.000003
12	8.76461	17.09474	8.380948	7.23809	10.572097
14	6.09524	11.428605	11.0476	6.09524	8.6666712
16	7.61904	17.904748	7.238095	8.38095	10.285708
18	6.47619	8.761905	9.904765	1.85714	8
20	4.95238	20.57138	9.904765	1.09523	10.380938
25	7.2381	10.285715	6.47619	9.14286	8.2857162
30	4.999522	9.14289	8.00002	8	7.535608
35	6.85714	15.2381	8.38095	9.142855	9.9047612
40	5.71428	7.619095	6.85714	7.2381	6.8571412
45	-------	5.71429	7.61905	------	6.66667
50	-------	14.85717	6.85714	9.523805	10.412705
60	7.2381	6.857148	6.095242	8	7.0476225

C-7. X Mean Error

TRIAL	CON	RANDY	DENNIS	JOHN	AVG
1	1.2579	3.0238	1.2585	-.3343	1.301475
2	.8498	-.4487	1.5165	-.3886	.38225
3	1.1667	-.7691	4.2008	.1477	1.186525
4	.9561	-1.1270	.8997	1.0397	.442125
5	.5641	.6349	1.3853	.3537	.7345
6	-.1524	-3.9958	1.4199	.2799	-.6121
7	.2594	.6811	1.5556	1.2239	.93
8	.8241	-.1244	.5677	.7075	.493725
9	.2566	-.6349	1.2340	.1240	.244925
10	.6324	.6407	-.2698	-.2362	.191775
12	1.2678	-1.0942	.8665	-1.4933	-.1133
14	.4114	.3632	.6984	1.2517	.681175
16	.6933	-.3556	2.5656	.6349	.88455
18	.9228	.5079	1.3212	-.4458	.576525
20	.1378	-1.7213	1.7330	-.3905	-.06025
25	.5867	-.6440	1.7479	2.0806	.9428
30	.7010	-2.2080	1.2021	0	-.076225
35	.1399	.2981	2.8531	1.5537	1.2112
40	.4267	1.7063	1.2595	1.8375	1.3075
45	-----	1.5138	1.4410	------	1.4774
50	1.4772	1.1905	2.1249	------	1.5975333
60	.1459	.9280	2.2933	1.0590	1.10655

C-8. Y Mean Error

TRIAL	CON	RANDY	DENNIS	JOHN	AVG
1	2.9686	2.4524	1.8367	1.0185	2.06905
2	1.1209	3.2508	2.8645	.0762	1.8281
3	.5079	3.7161	3.8919	.2721	2.097
4	.0523	4.2063	4.3040	.2619	2.206125
5	1.9707	5.1534	4.4848	2.24399	3.4632225
6	1.5619	6.1460	4.4069	.5753	3.172525
7	-.3485	7.8038	4.9127	2.3911	3.689775
8	2.2157	6.0175	3.5033	1.3061	3.26065
9	-.6764	4.1111	5.1263	-.1506	2.1026
10	1.3181	5.5931	3.3730	2.5448	3.20725
12	1.4150	5.1307	2.9729	1.1124	2.65775
14	.7086	5.3333	3.9444	-.1399	2.4616
16	2.2171	4.9101	4.8824	.4762	3.12145
18	-.0254	4.3344	4.8227	1.3374	2.617275
20	.6403	3.1746	4.9374	-1.0571	1.9238
25	1.7067	3.2744	2.2558	1.2088	2.111425
30	2.6133	5.2400	2.4296	.9264	2.802325
35	3.33897	4.7536	1.6211	1.4641	.2809375
40	2.9333	2.3095	3.8717	.9785	2.52325
45	------	4.3910	3.5611	------	3.97605
50	1.4772	1.2857	2.9884	------	1.9171
60	.8835	2.3834	2.2781	1.5848	1.7245

C-9. X Adjusted Error

TRIAL	CON	RANDY	DENNIS	JOHN	AVG
1	.9561	3.2856	.6840	-.2372	1.1721255
2	.6769	-.2429	.6562	2.2252	.21625
3	.6407	-.5759	3.0298	.0330	.7819
4	.7567	-.9123	.6261	.6389	.27735
5	.4786	-.0618	.9062	.1514	.3686
6	-.1328	-2.3095	.8689	.0753	-.374525
7	.2140	.5007	1.0475	.5527	.578725
8	.5668	-.0728	.2328	.3547	.270375
9	.1418	-.3861	.8599	.0414	.16425
10	.5536	.5847	-.1912	-.1191	.207
12	.9203	-.8820	.3510	-.6596	-.067575
14	.2432	.2523	.4664	1.0063	.49205
16	.5478	-.2145	1.4048	.2817	.50495
18	.5179	.4228	.9447	-.2168	.41715
20	.1321	.2667	1.2170	-.1100	.37645
25	.4001	-.4416	.8934	.5527	.35115
30	.3828	-1.1173	.6613	.0521	-.005275
35	.0724	.1287	1.1096	.9694	.570025
40	.1625	.9222	.4938	1.2586	.709275
45	-----	.8635	1.1411	------	1.0023
50	.7231	.6988	1.2891	------	.9053
60	.0866	.7032	.8031	.5745	.54235

C-10. Y Adjusted Error

TRIAL	CON	RANDY	DENNIS	JOHN	AVG
1	1.4735	.8037	.9929	.4072	.919325
2	.2406	1.2232	1.6815	.0465	.82295
3	.1527	1.0072	1.9576	.1322	.812425
4	.0596	1.1279	1.8575	.0415	.771625
5	.4973	.3801	1.4372	1.2143	.882225
6	.7934	.9326	2.4015	.2062	1.083425
7	-.1474	1.3542	2.5019	.7011	1.10295
8	.9569	1.4183	1.5830	.3114	1.0674
9	-.2449	.7024	3.6255	-.0487	1.008575
10	.3936	1.5989	1.1557	.5730	.9303
12	.5068	1.0052	1.4806	.2675	.815025
14	.2679	1.4549	2.2053	-.0340	0.973525
16	.5309	2.0380	2.2034	.1421	1.29286
18	.0286	1.6159	2.2504	.2153	1.02755
20	.3443	.8269	.7623	-.4884	.361275
25	.7430	1.9344	.7776	.1899	.911225
30	.9192	1.5304	1.1006	.2368	.95925
35	1.2102	1.2275	.5125	.3342	.8361
40	.9536	.4897	2.4203	.2150	1.01965
45	------	1.1443	1.6696	-----	1.40695
50	1.1541	.2147	.6555	-----	.67476666
60	.4977	.6984	.9848	.6679	.7122

C-11. X Autocorrelations

TRIAL	CON	RANDY	DENNIS	JOHN	AVG
1	.2908	0	.4539	.3567	.361713
2	.2758	.3776	.6264	.4607	.435125
3	.4179	.3340	.2882	.3633	.36435
4	.2295	.1625	.3471	.3732	.278075
5	.1724	.7097	.3942	.5513	.4569
6	.2248	.4431	.4470	.6129	.43195
7	.3024	.7715	.3417	.5733	.497225
8	.3172	.2082	.6226	.5302	.41955
9	.3613	.4653	.3226	.2861	.358825
10	.2186	.0556	.2477	.5063	.2563
12	.3128	.2210	.5788	.5722	.4212
14	.3396	.1766	.3385	.2363	.27275
16	.2107	.2891	.4789	.5398	.379625
18	.4806	.2778	.3177	.5365	.40315
20	.1306	.8110	.2940	.5812	.5549875
25	.3649	.3618	.5185	.7607	.501475
30	.3835	.4720	.5118	.5580	.481325
35	.4375	.5540	.6281	.3694	.49725
40	.6157	.4943	.6483	.3176	.452075
45	-----	.4599	.2373	-----	.3486
50	.5065	.4606	.3896	-----	.45223
60	.4081	.3062	.8031	.4701	.496875

C-12. Y Autocorrelations

TRIAL	CON	RANDY	DENNIS	JOHN	AVG
1	.5244	.6913	.4967	.6416	.5885
2	.6824	.6827	.4326	.5582	.588979
3	.8211	.7415	.5249	.7039	.69785
4	.8190	.7627	.5927	.8640	.7596
5	.7697	1.0000	.7004	.5367	.7517
6	.5199	.8468	.4791	.6627	.627125
7	.7566	.8682	.5144	.7364	.71865
8	.5690	.7977	.5658	.7893	.68045
9	.5697	.8616	.3021	.8047	.634525
10	.7307	.7440	.6644	.8126	.737925
12	.6675	.8179	.5110	.8224	.7047
14	.6690	.7684	.4436	.6893	.642575
16	.7594	.6176	.5594	.8072	.6949
18	.5653	.6530	.5648	.8611	.66255
20	.5174	.8896	.8890	.5588	.7137
25	.5891	.4415	.6948	.8572	.64565
30	.6814	.7187	.5618	.7761	.6845
35	.6848	.7803	.6729	.7945	.733125
40	.6934	.8112	.3902	.8304	.6813
45	-----	.7726	.5567	-----	.66465
50	.7158	.9398	.8155	-----	.8237
60	.4586	.7393	.9848	.5842	.691725

C-13. Y Standard Deviation of Error

TRIAL	CON	RANDY	DENNIS	JOHN	AVG
1	2.1030	3.0374	1.6773	1.5404	2.089525
2	2.4968	2.8848	1.3077	1.3638	2.013275
3	2.3658	2.2561	2.2824	1.4083	2.07815
4	1.8663	2.5524	2.4999	1.7469	2.166375
5	1.8335	4.5673	1.7847	1.3385	2.381
6	1.7180	5.5298	2.0937	1.3978	2.684825
7	1.7382	4.2401	2.4866	1.5841	2.51225
8	1.6799	3.1663	2.2266	1.3735	2.111575
9	1.7871	2.8486	1.5132	1.4616	1.917625
10	1.8603	3.4081	2.1101	2.1583	2.3842
12	1.9734	4.5221	1.7274	1.7103	2.3583
14	1.7468	3.5484	2.0485	1.3235	2.1668
16	1.9602	3.654	1.6342	1.6495	2.224075
18	1.6771	2.3697	2.5223	1.7237	2.0732
20	1.4167	4.5970	2.4875	1.0225	2.380925
25	2.3949	1.8454	1.5292	1.6069	1.8441
30	1.8033	2.3121	1.8437	1.4660	1.871275
35	2.1143	3.2768	1.7234	1.6872	2.201675
40	1.8037	1.8098	1.4843	1.7109	1.702175
45	------	1.8594	1.6735	------	1.76645
50	1.9304	3.6915	1.7867	------	2.46953
60	1.8359	1.7231	1.3518	1.3476	1.5646

C-14. Y Adjusted Standard Deviation of Error

TRIAL	CON	RANDY	DENNIS	JOHN	AVG
1	1.7906	2.1948	1.4558	1.1815	1.655675
2	1.8251	2.1079	1.1790	1.1315	1.560875
3	1.3503	1.5138	1.9428	1.0004	1.461825
4	1.0710	1.6507	1.5866	.8795	1.29696
5	1.1706	0	1.2739	1.1294	1.1913
6	1.4675	2.9417	1.8389	1.0469	1.82376
7	1.1387	2.1038	2.1324	1.0718	1.611675
8	1.3815	1.9095	1.8358	.8433	1.492525
9	1.4194	1.4460	1.4997	.8677	1.3082
10	1.2700	2.2773	1.5771	1.2578	1.59555
12	1.4695	2.3144	1.4848	.9731	1.56045
14	1.2982	2.2709	1.8359	.9589	1.590975
16	1.1881	2.8524	1.6342	.9737	1.6621
18	1.3834	1.7947	2.0914	.8587	1.53205
20	1.2124	2.0998	1.1391	.2480	1.174825
25	1.9352	1.6558	1.0998	.8276	1.3796
30	1.3199	1.6494	1.5252	.9244	1.351725
35	1.5407	2.0495	1.2786	1.0245	1.473325
40	1.2996	1.0582	1.3666	1.7109	1.358825
45	------	1.1805	1.3903	------	1.2854
50	1.3479	1.2613	1.0341	------	1.21443
60	1.6313	1.1604	1.1016	1.3476	1.310225

C-15. X Standard Deviation of Error

TRIAL	CON	RANDY	DENNIS	JOHN	AVG
1	4.2124	5.6007	2.5898	2.4487	3.7129
2	3.4920	6.5220	2.5241	3.0529	3.89775
3	3.0702	5.2449	3.0257	2.1122	3.36325
4	2.2126	4.4189	2.4999	1.8889	2.755075
5	1.8113	7.8670	2.0932	2.8050	3.644125
6	2.2306	5.7675	2.6551	1.8414	3.12365
7	2.4199	11.4070	3.2599	2.1564	4.8108
8	2.4385	3.8689	2.7706	2.1953	2.818325
9	1.8718	2.8695	2.3098	1.6909	2.1855
10	1.8076	3.1722	2.0582	2.0892	2.2818
12	2.2354	3.3622	2.5838	1.6360	2.45435
14	2.4711	2.5090	2.6280	2.1480	2.439025
16	1.5711	3.4171	2.1798	2.0662	2.308625
18	2.2734	2.9149	1.9406	2.1525	2.32035
20	1.8191	6.6399	1.7878	2.1541	3.100225
25	2.3949	2.9225	2.2242	1.8486	2.34755
30	2.0542	2.9272	1.9407	2.1171	2.2598
35	1.7049	3.6908	1.7108	1.9467	2.2633
40	2.2631	2.7739	1.9287	2.1586	2.281075
45	-----	2.4134	1.6735	------	2.04345
50	2.4164	3.5377	1.8583	------	2.6041333
60	2.3221	2.4747	1.8518	2.1949	2.210875

C-16. X Adjusted Standard Deviation of Error

TRIAL	CON	RANDY	DENNIS	JOHN	AVG
1	4.0314	5.5958	2.3076	2.2876	3.5556
2	3.3565	6.0392	1.9676	2.7097	3.51825
3	.27069	4.9438	2.8973	1.9638	3.12795
4	2.1536	4.3602	2.3445	1.7524	2.652675
5	1.7842	5.5424	1.9237	2.3402	2.897625
6	2.1735	5.1703	2.3750	1.4550	2.79345
7	2.3067	7.2576	3.0637	1.7669	3.598725
8	2.3125	3.7841	2.1682	1.8614	2.53155
9	1.7459	2.5399	2.1863	1.6202	2.023075
10	1.7639	3.1673	1.9956	1.8016	2.1821
12	2.1236	3.2791	2.1070	1.3417	2.21275
14	2.3242	2.4696	2.4728	2.0871	2.338425
16	1.5358	3.2715	1.9135	1.7393	2.115025
18	1.9936	2.8001	1.8401	1.3374	1.9928
20	1.8035	3.8848	1.7084	1.7530	2.287425
25	2.2147	2.7245	1.9018	1.2000	2.01025
30	1.8971	2.5806	1.6673	1.7568	1.97545
35	1.5331	3.0725	1.3313	1.8090	1.936475
40	1.7833	2.4114	1.4686	2.0469	1.92755
45	------	2.1430	1.6604	------	1.9017
50	2.0835	3.1402	1.7115	------	2.311733
60	2.1199	2.3559	1.3833	1.9372	1.949075

APPENDIX D

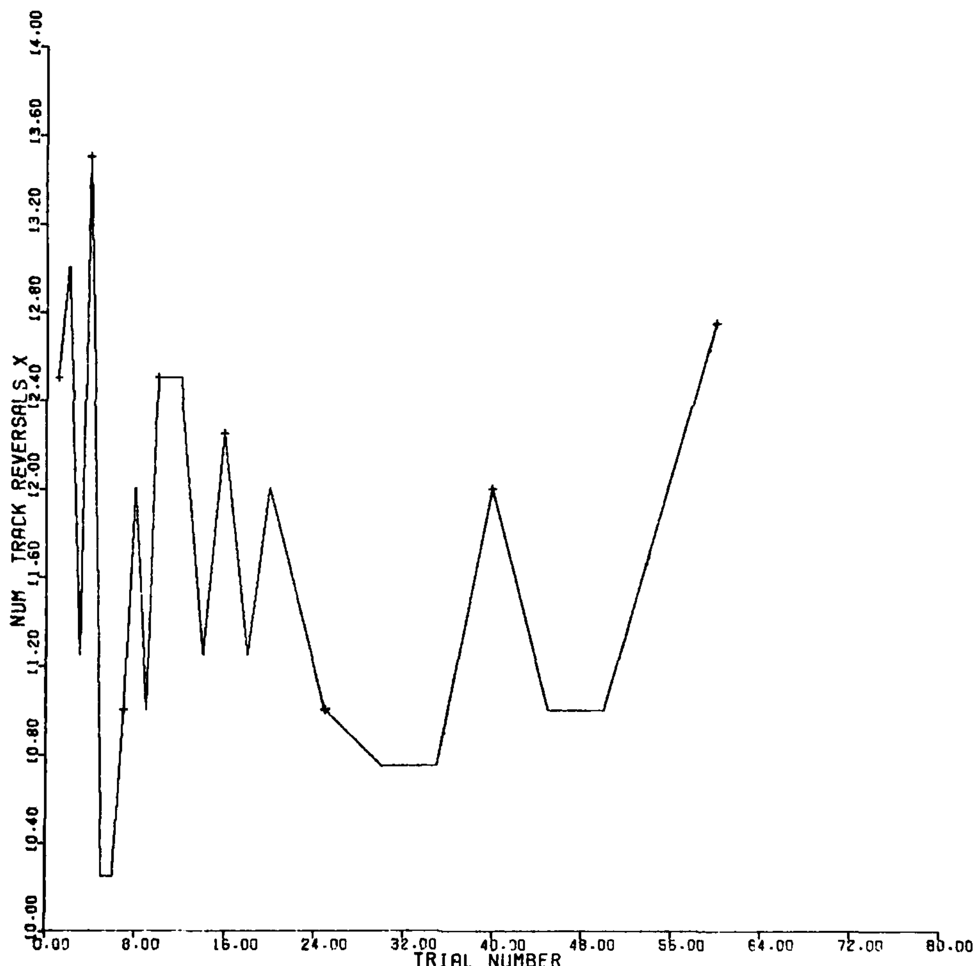


Figure D-1. X Reversals vs. Trial Number

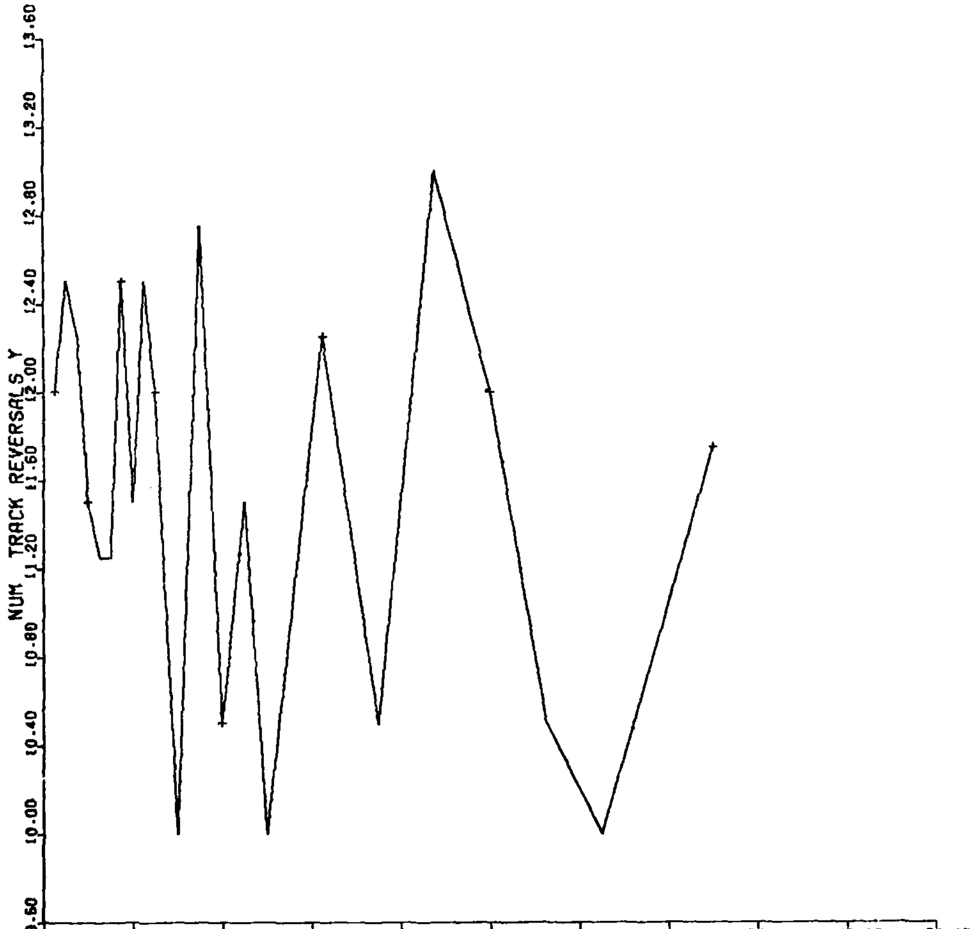


Figure D-2. Y Reversals vs. Trial Number

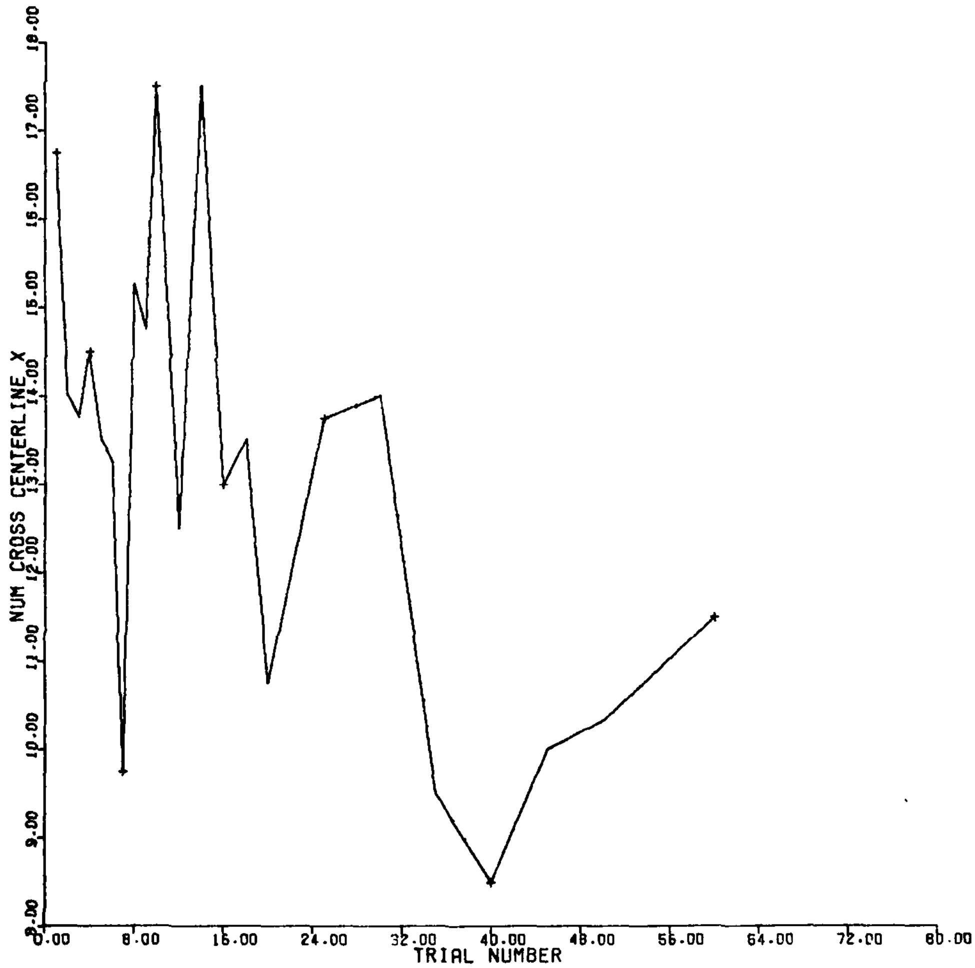


Figure D-3. X Crossovers vs. Trial Number

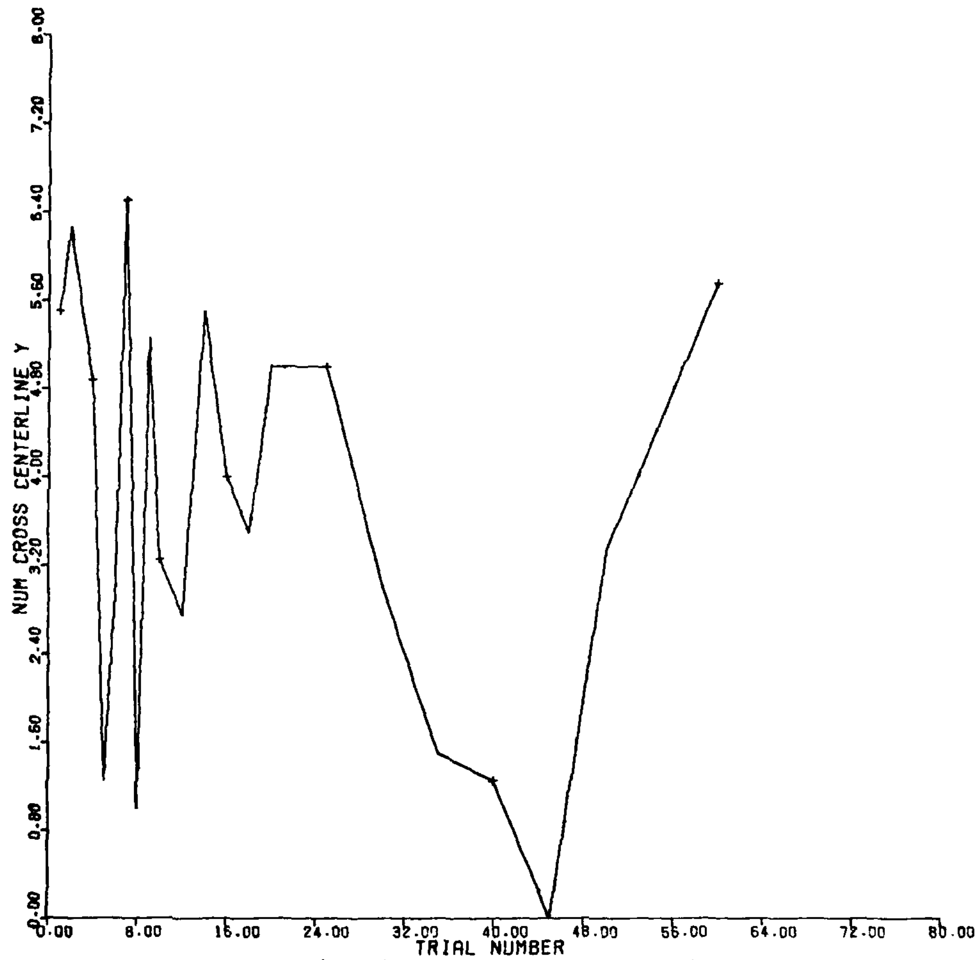


Figure D-4. Y Crossovers vs. Trial Number

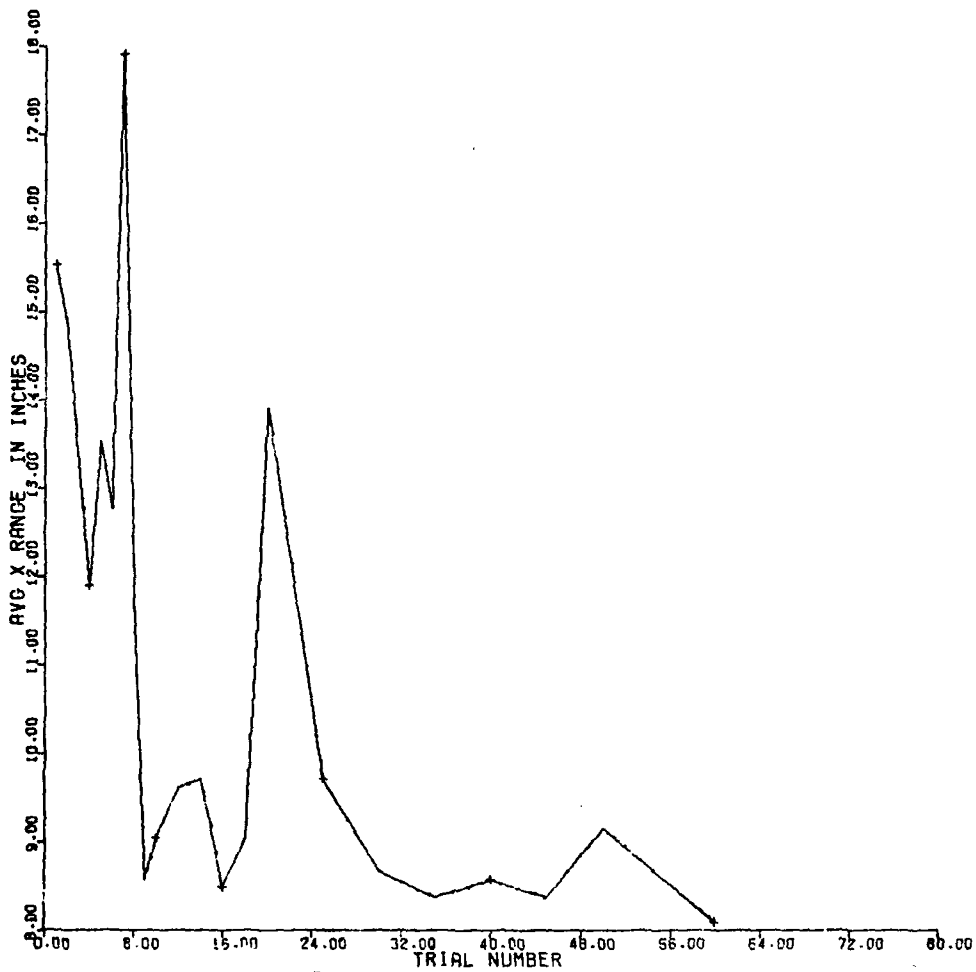


Figure D-5. X Error Range vs. Trial Number

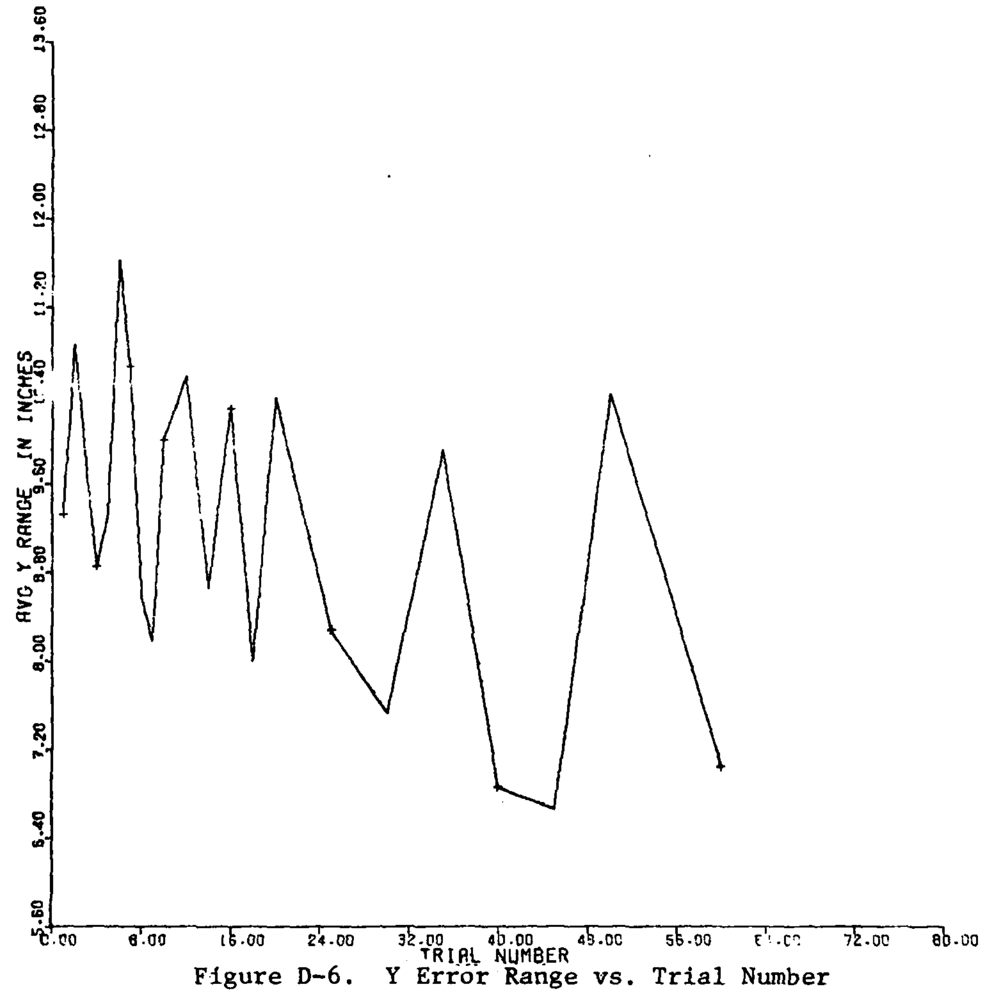


Figure D-6. Y Error Range vs. Trial Number

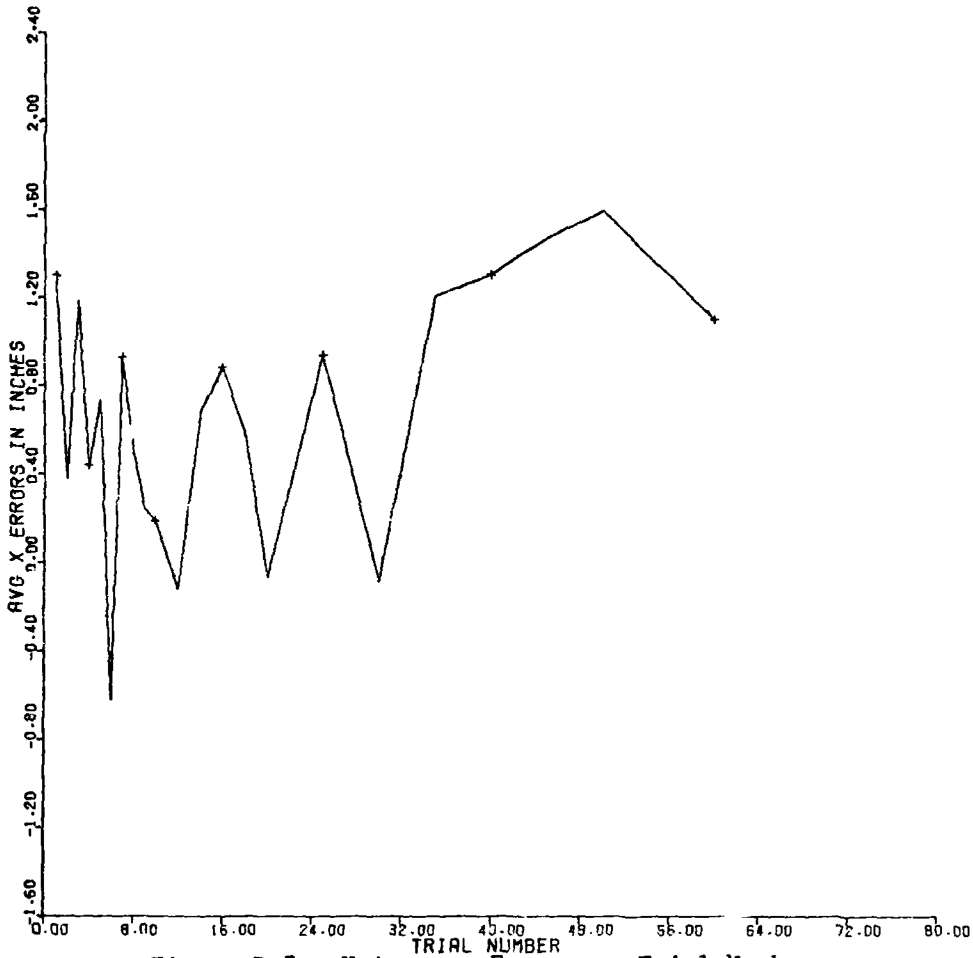


Figure D-7. X Average Error vs. Trial Number

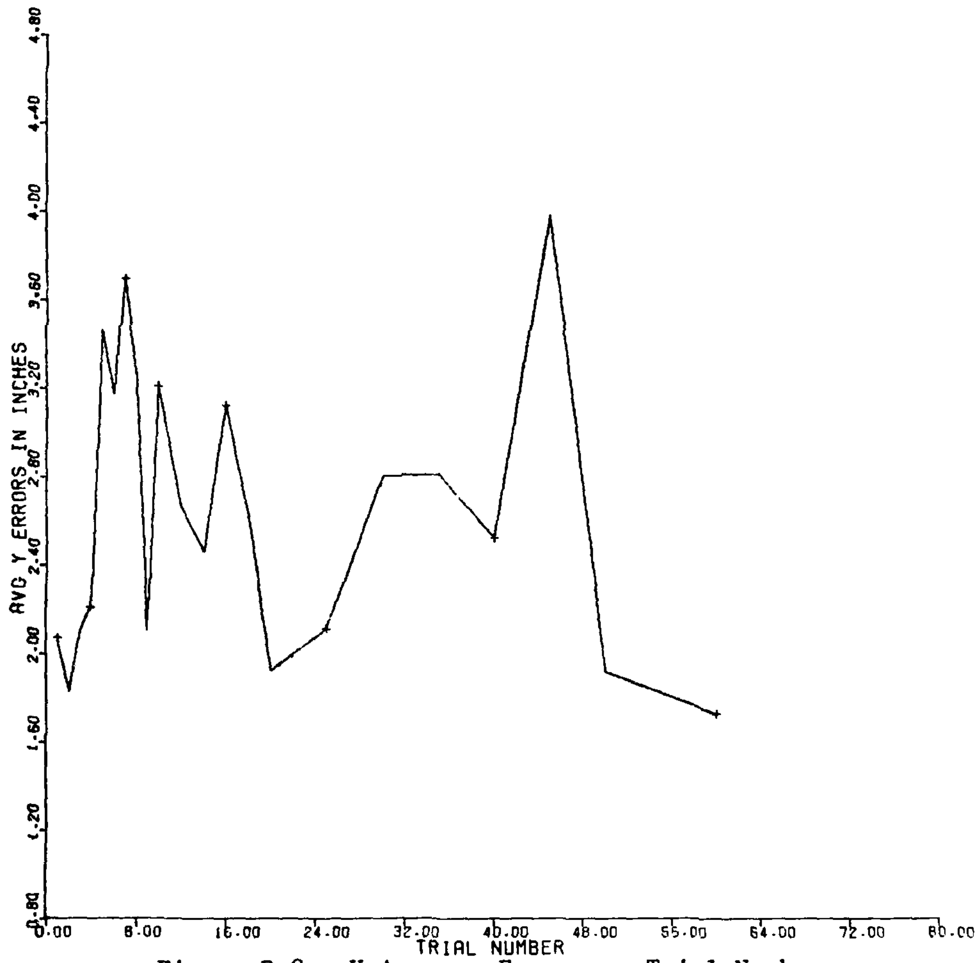


Figure D-8. Y Average Error vs. Trial Number

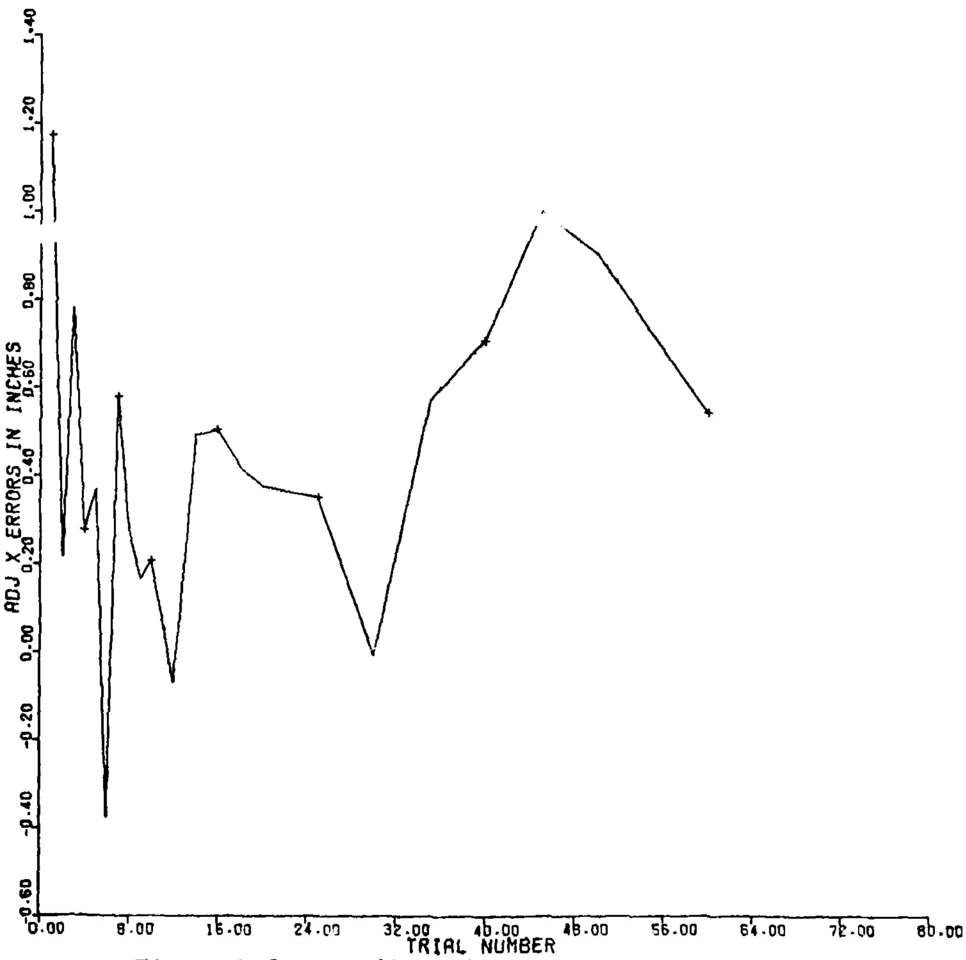


Figure D-9. X Adjusted Error vs. Trial Number

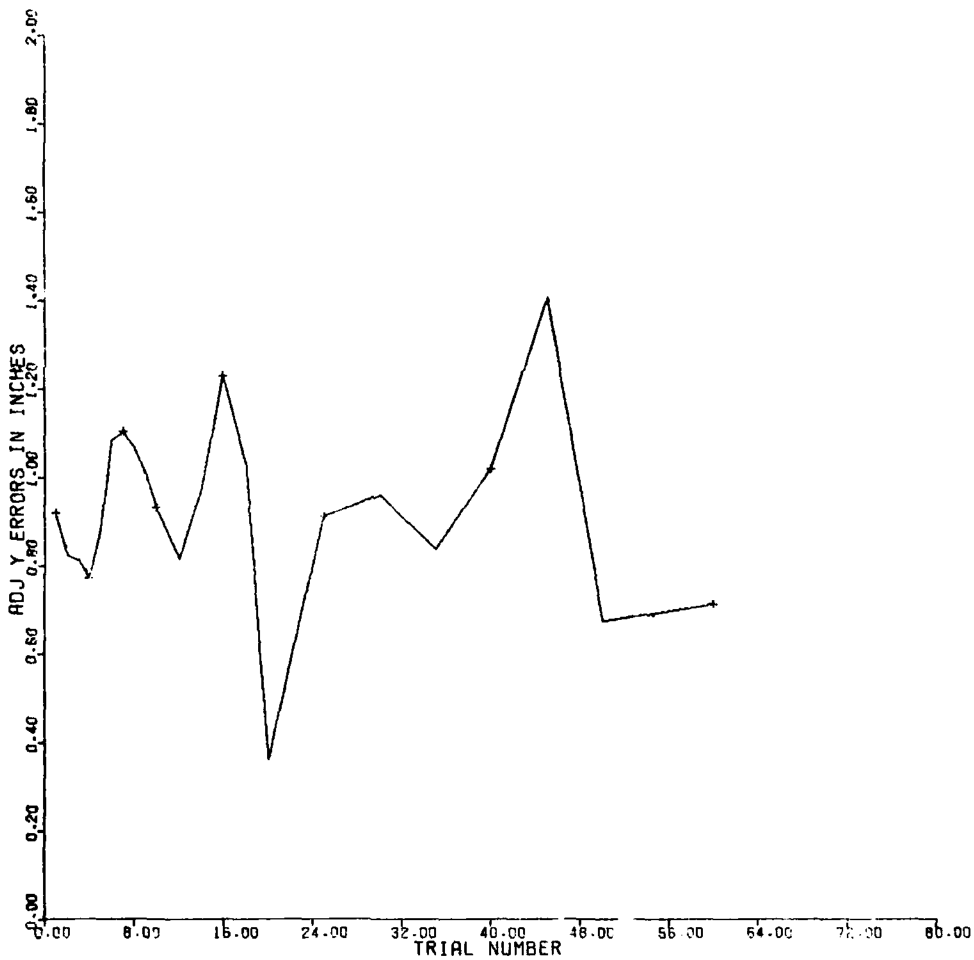


Figure D-10. Y Adjusted Error vs. Trial Number

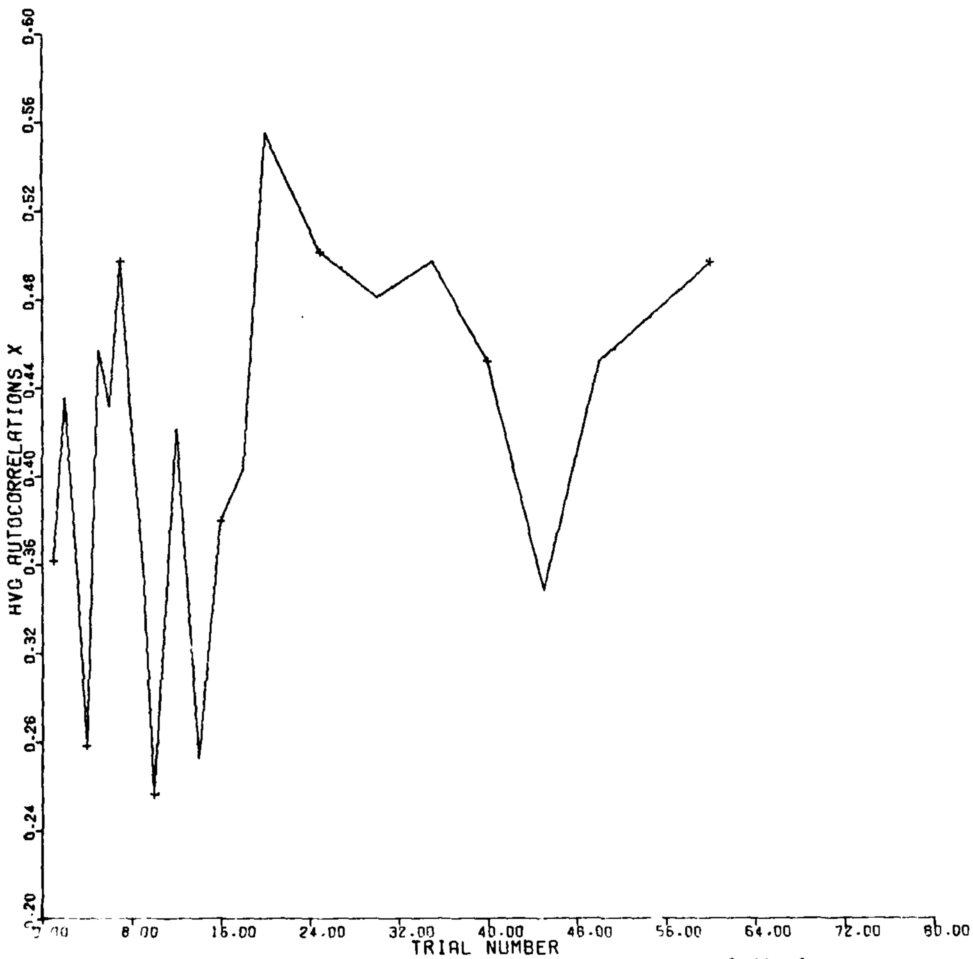


Figure D-11. X Autocorrelation vs. Trial Number

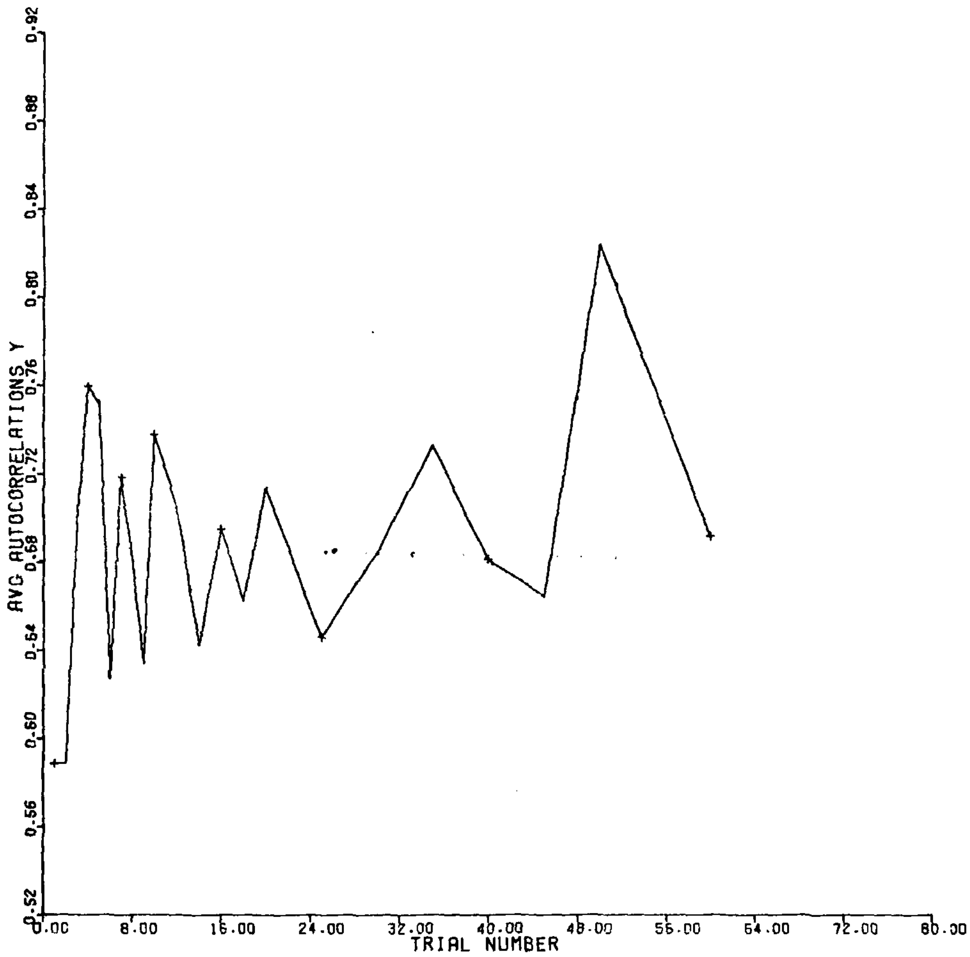


Figure D-12. Y Autocorrelation vs. Trial Number

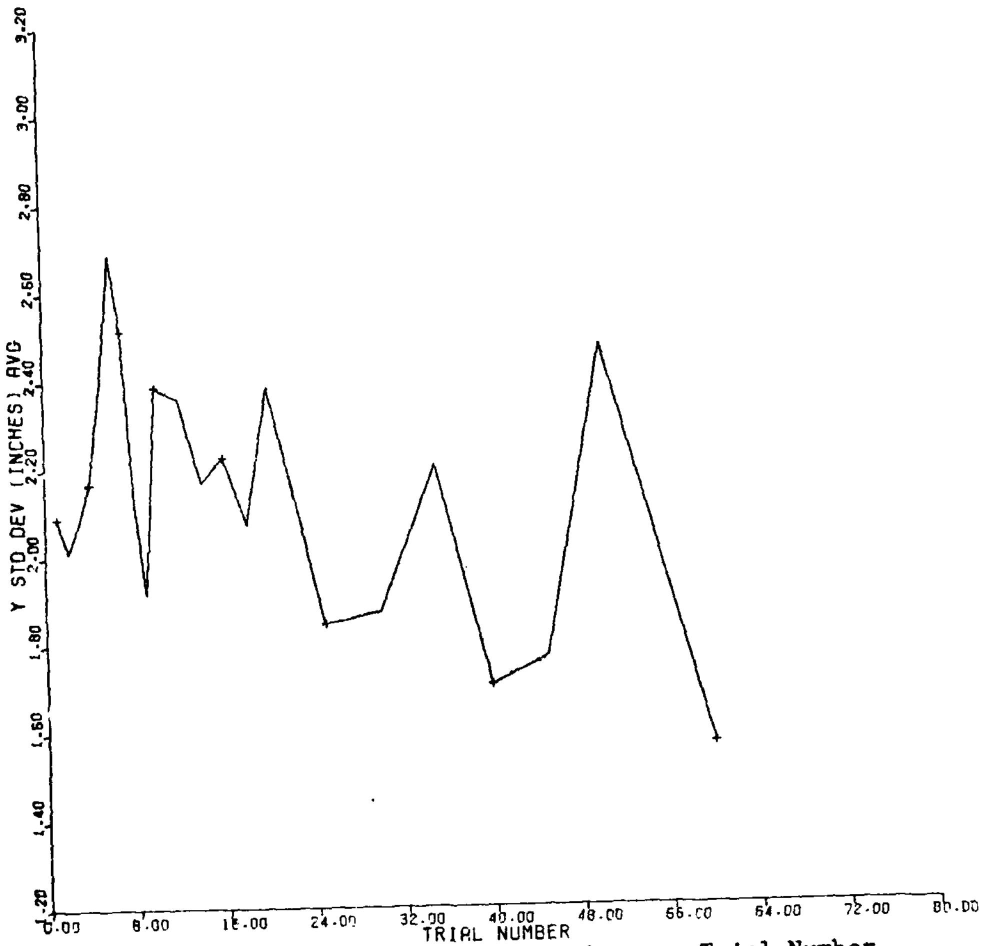


Figure D-13. Y Standard Deviation vs. Trial Number

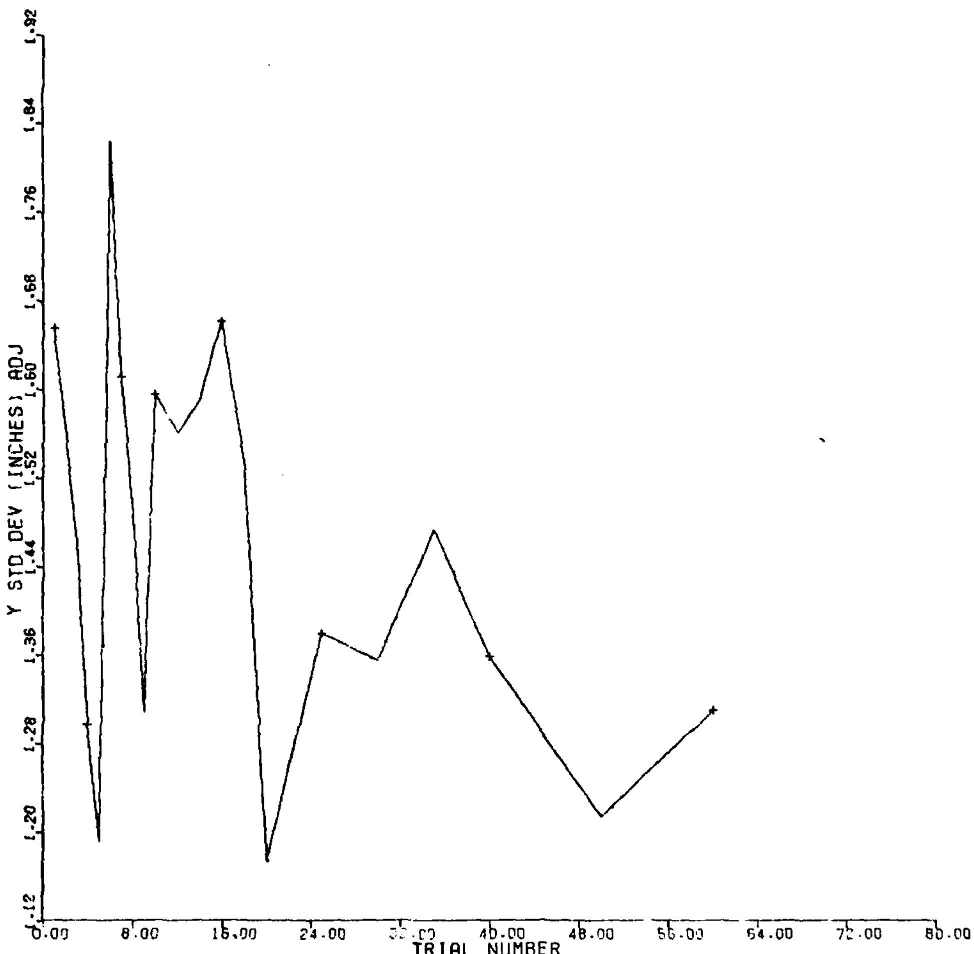


Figure D-14. Y Adjusted Standard Deviation vs. Trial Number

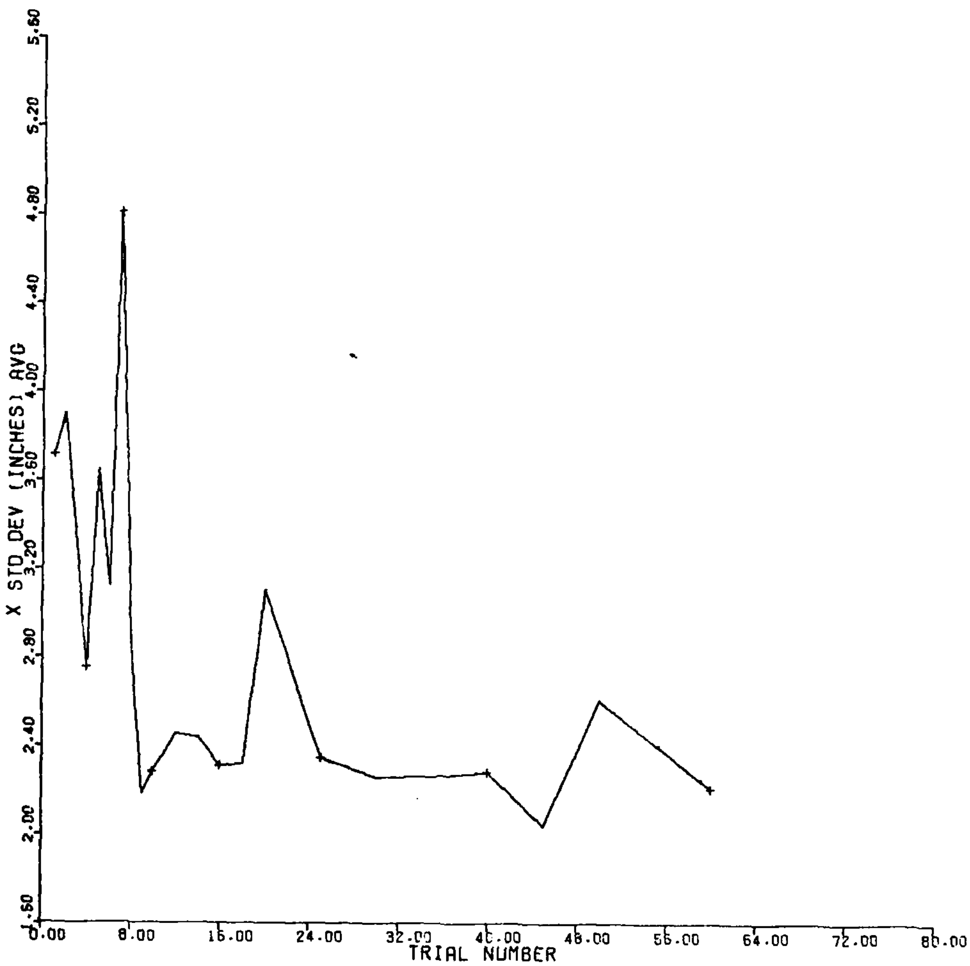


Figure D-15. X Standard Deviation vs. Trial Number

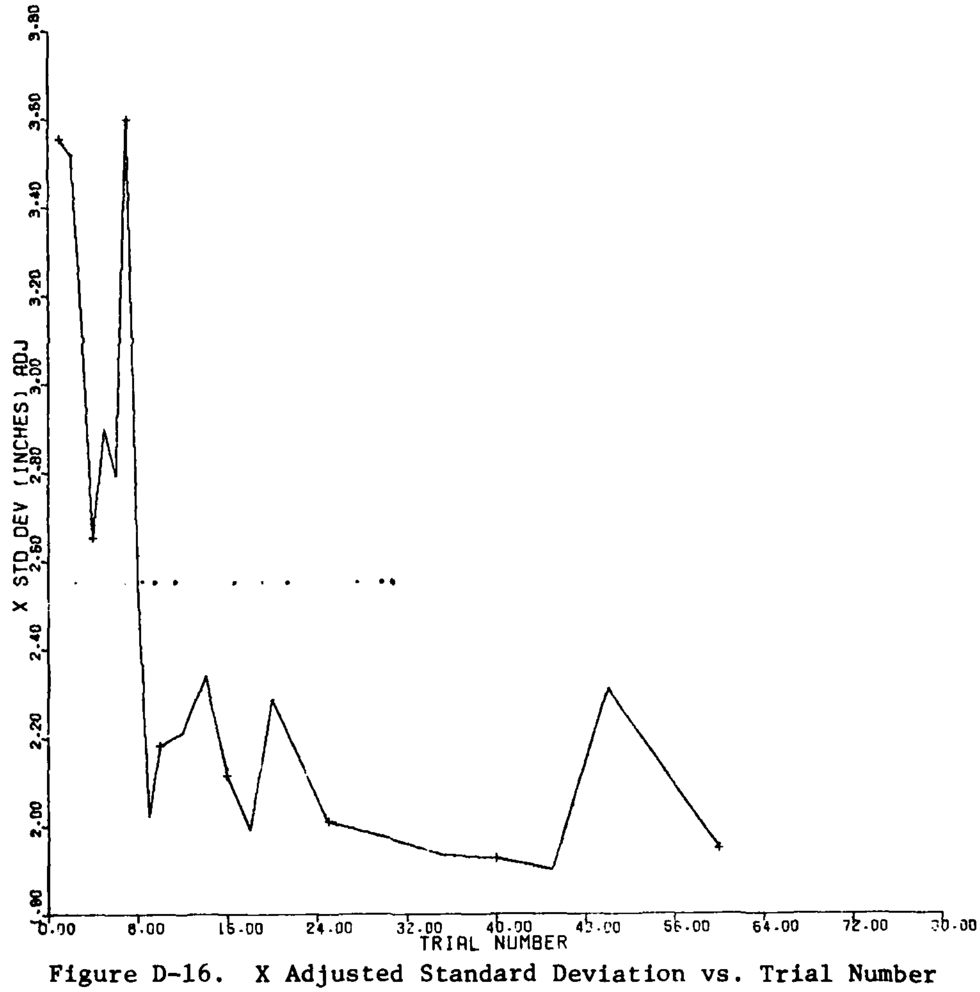


Figure D-16. X Adjusted Standard Deviation vs. Trial Number

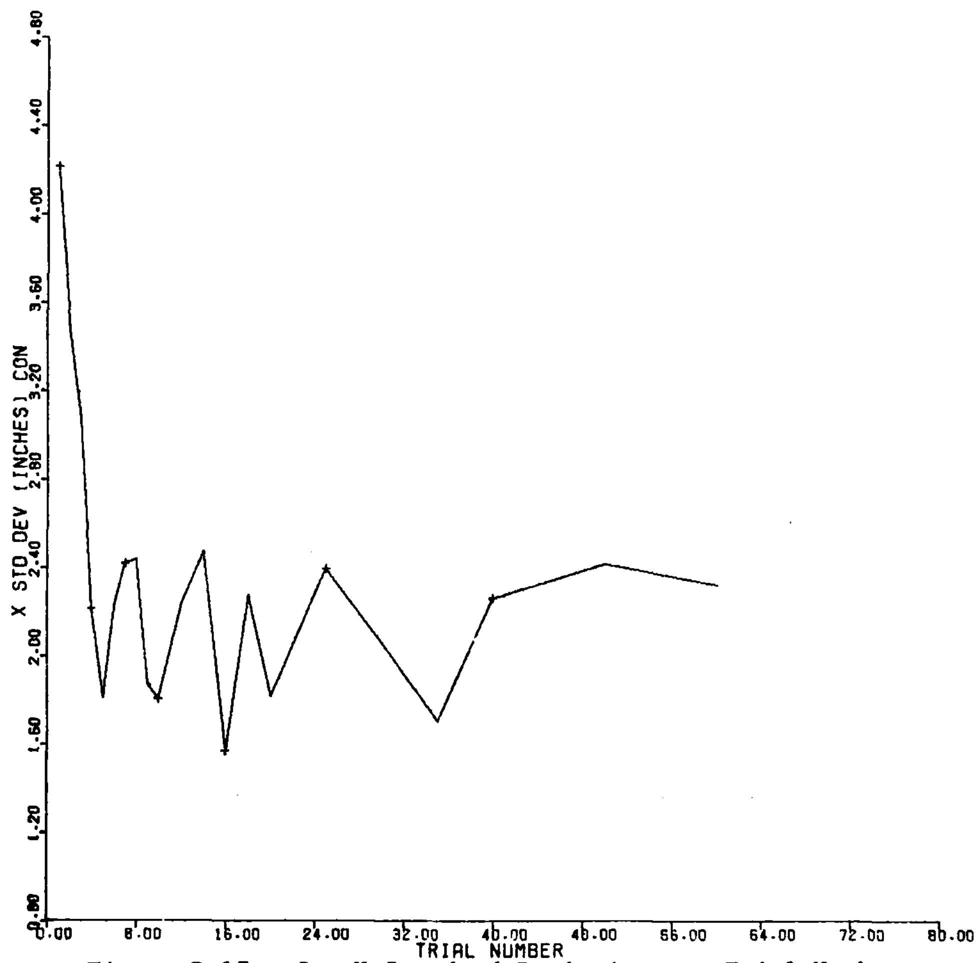


Figure D-17. Con X Standard Deviation vs. Trial Number

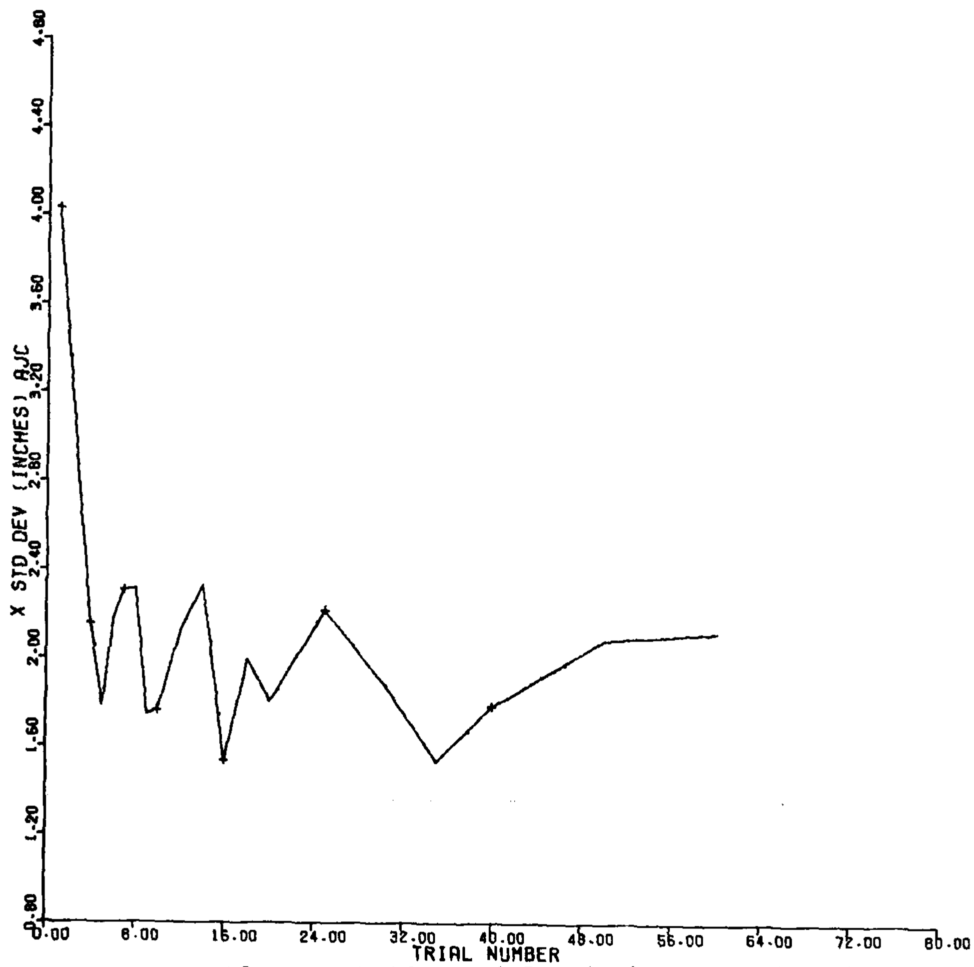


Figure D-18. Con X Adjusted Standard vs. Trial Number

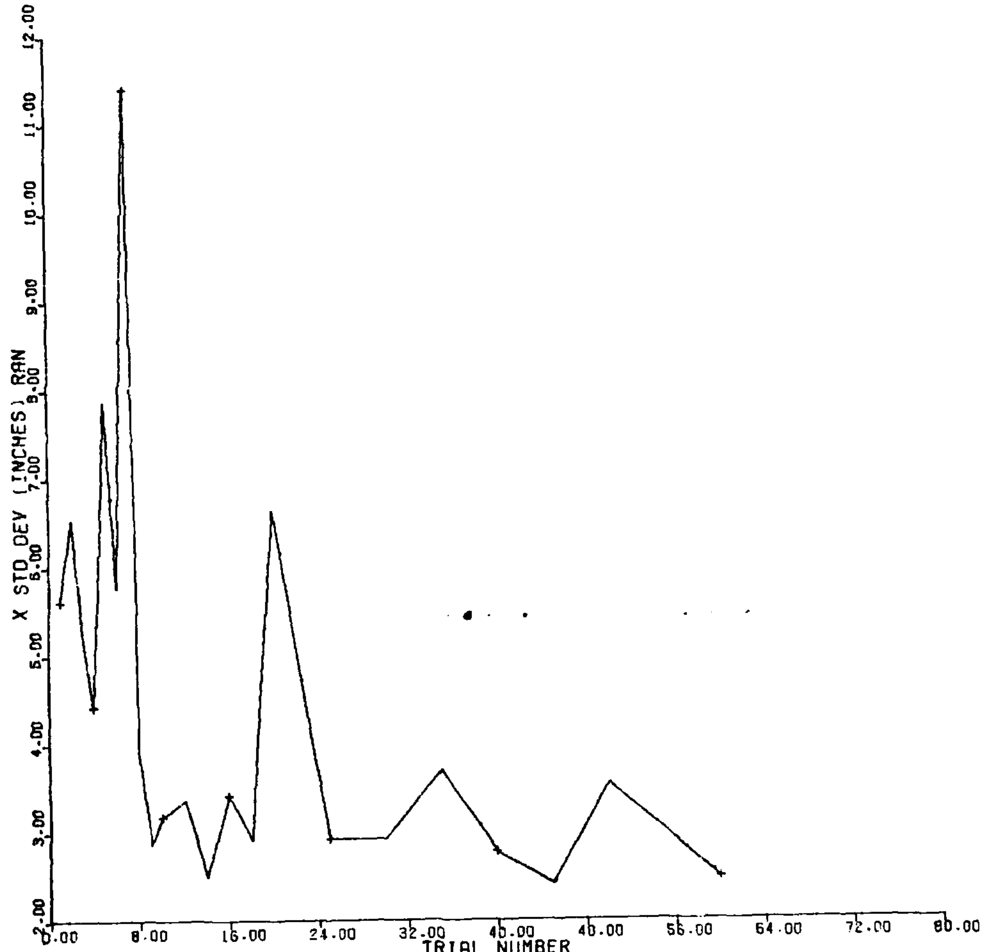


Figure D-19. Randy X Standard Deviation vs. Trial Number

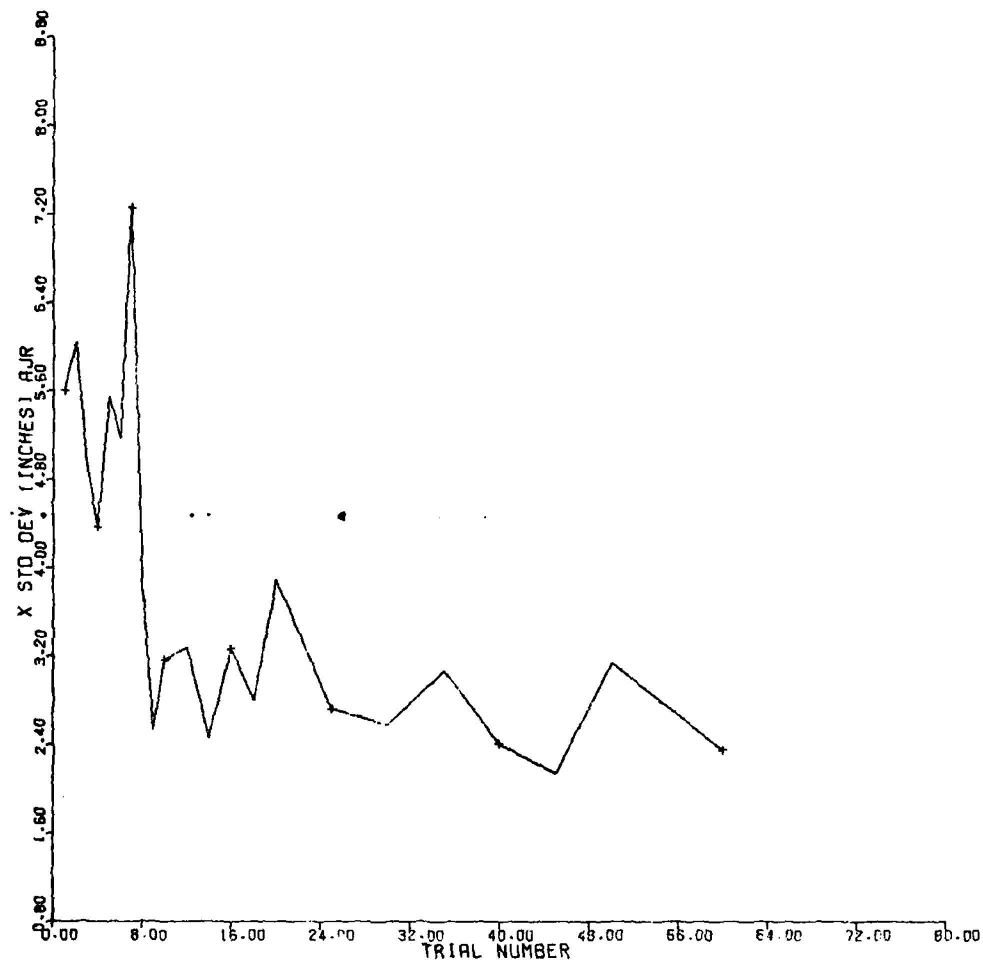


Figure D-20. Randy X Adjusted Standard Deviation vs. Trial Number

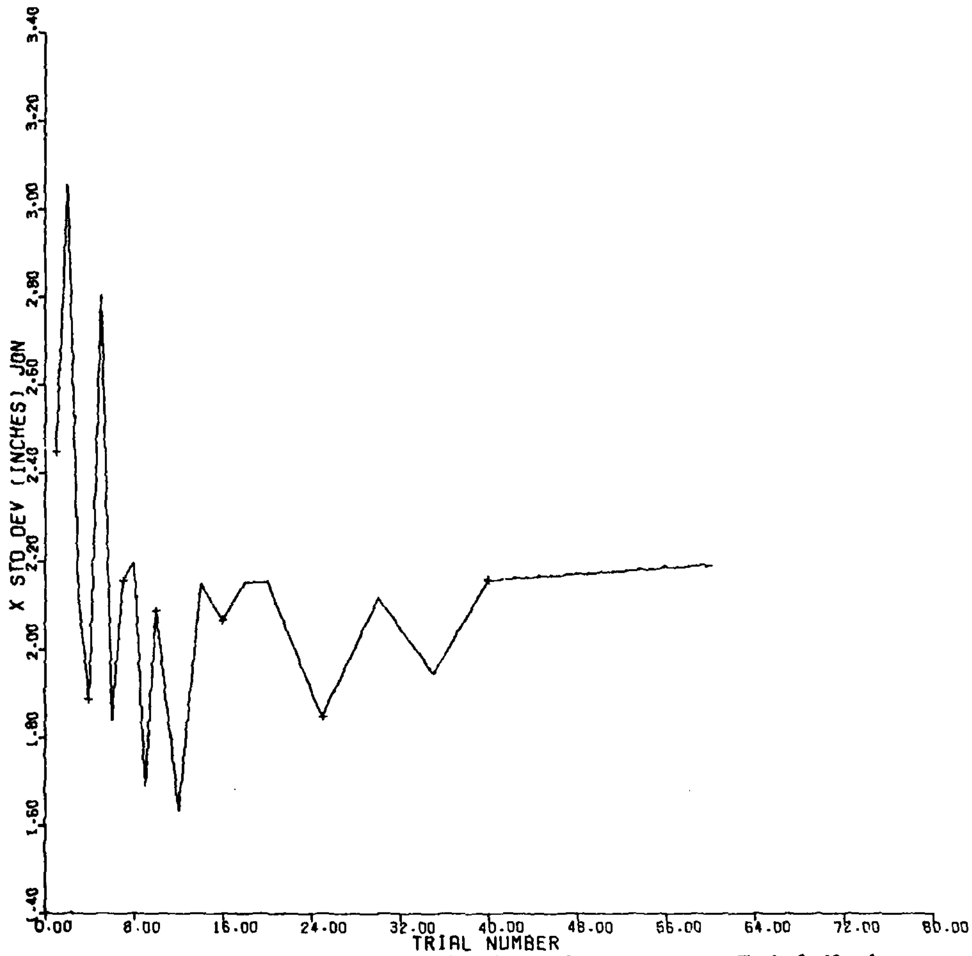


Figure D-21. John X Standard Deviations vs. Trial Number

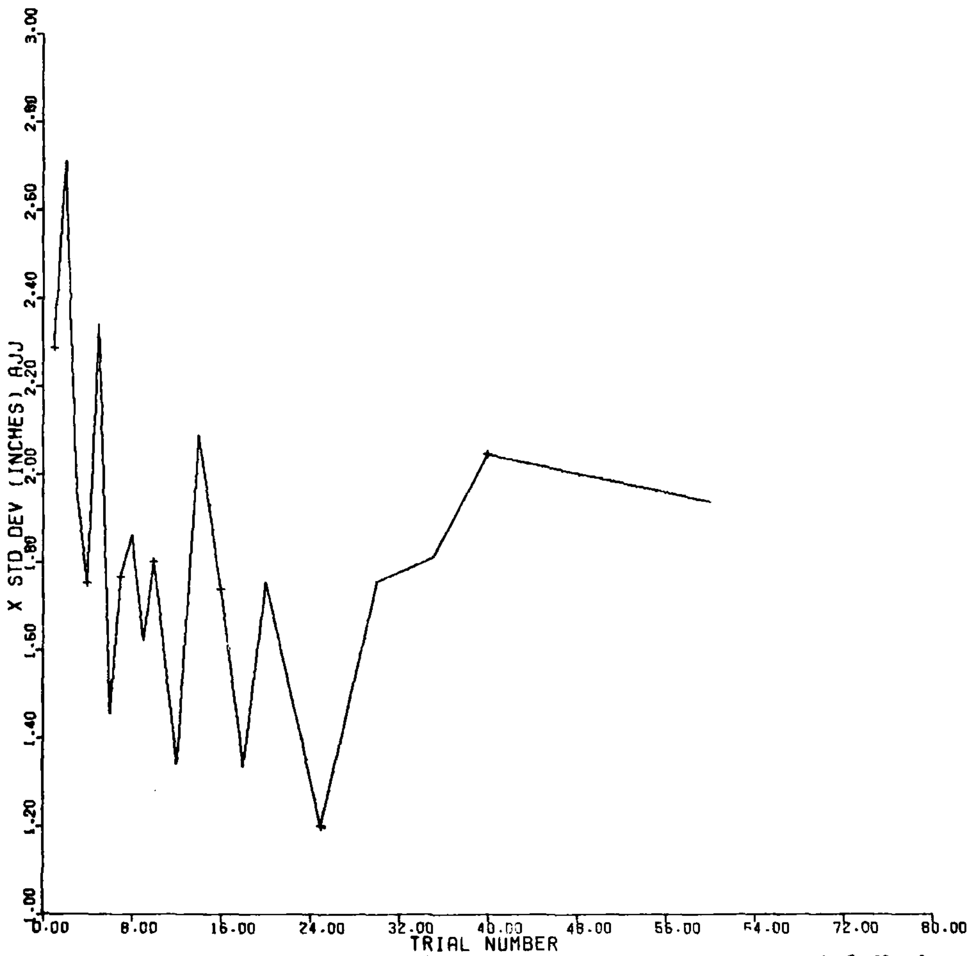


Figure D-22. John X Adjusted Standard Deviation vs. Trial Number

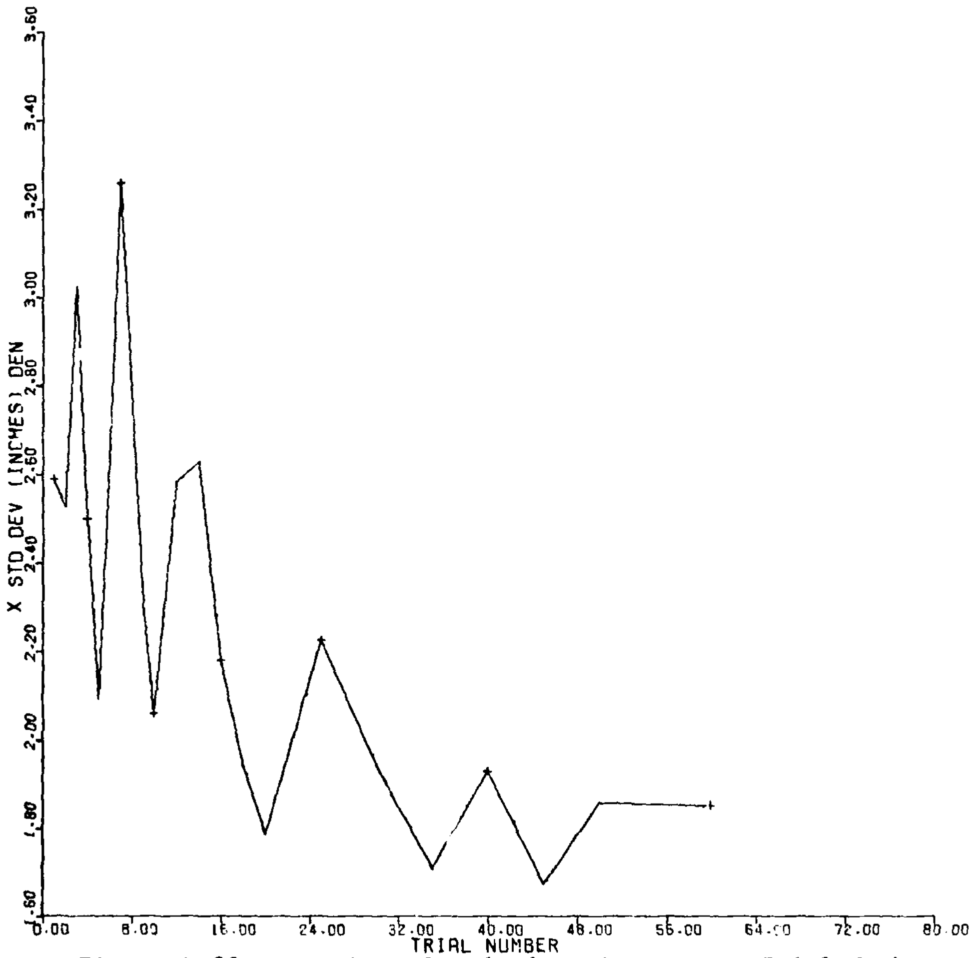


Figure D-23. Dennis X Standard Deviation vs. Trial Number

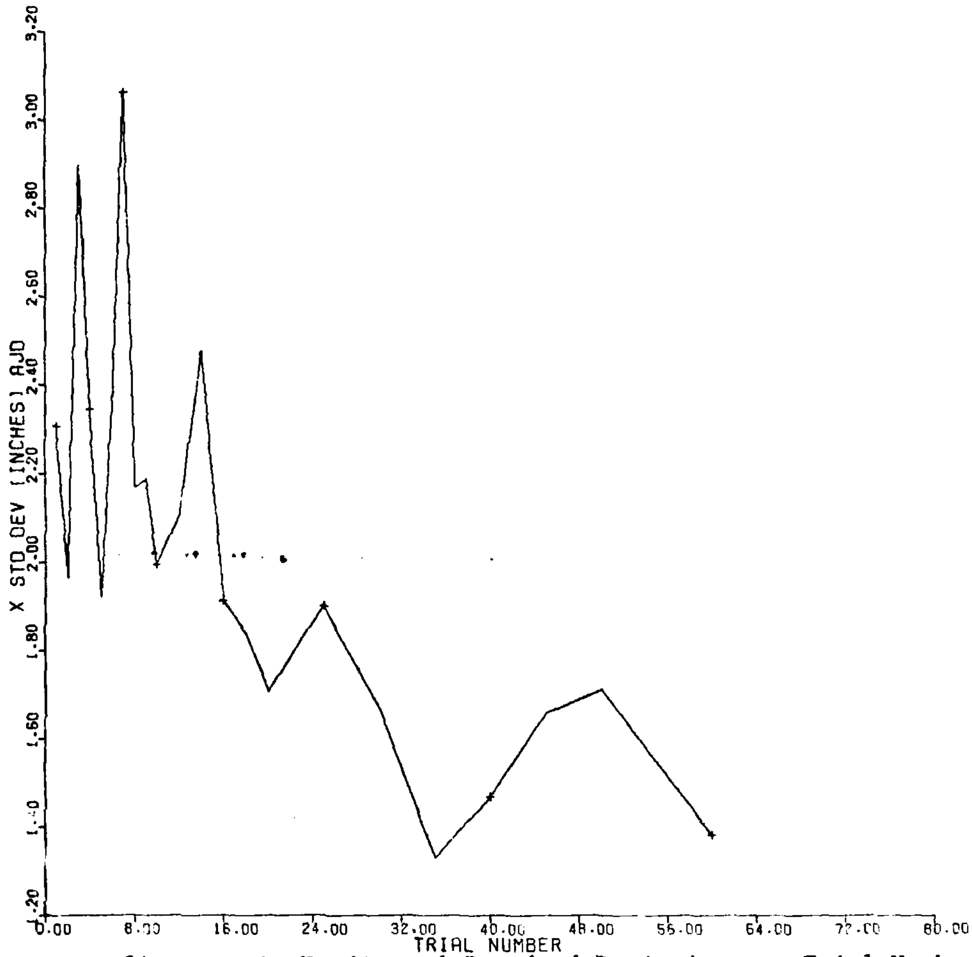


Figure D-24. Dennis X Adjusted Standard Deviation vs. Trial Number

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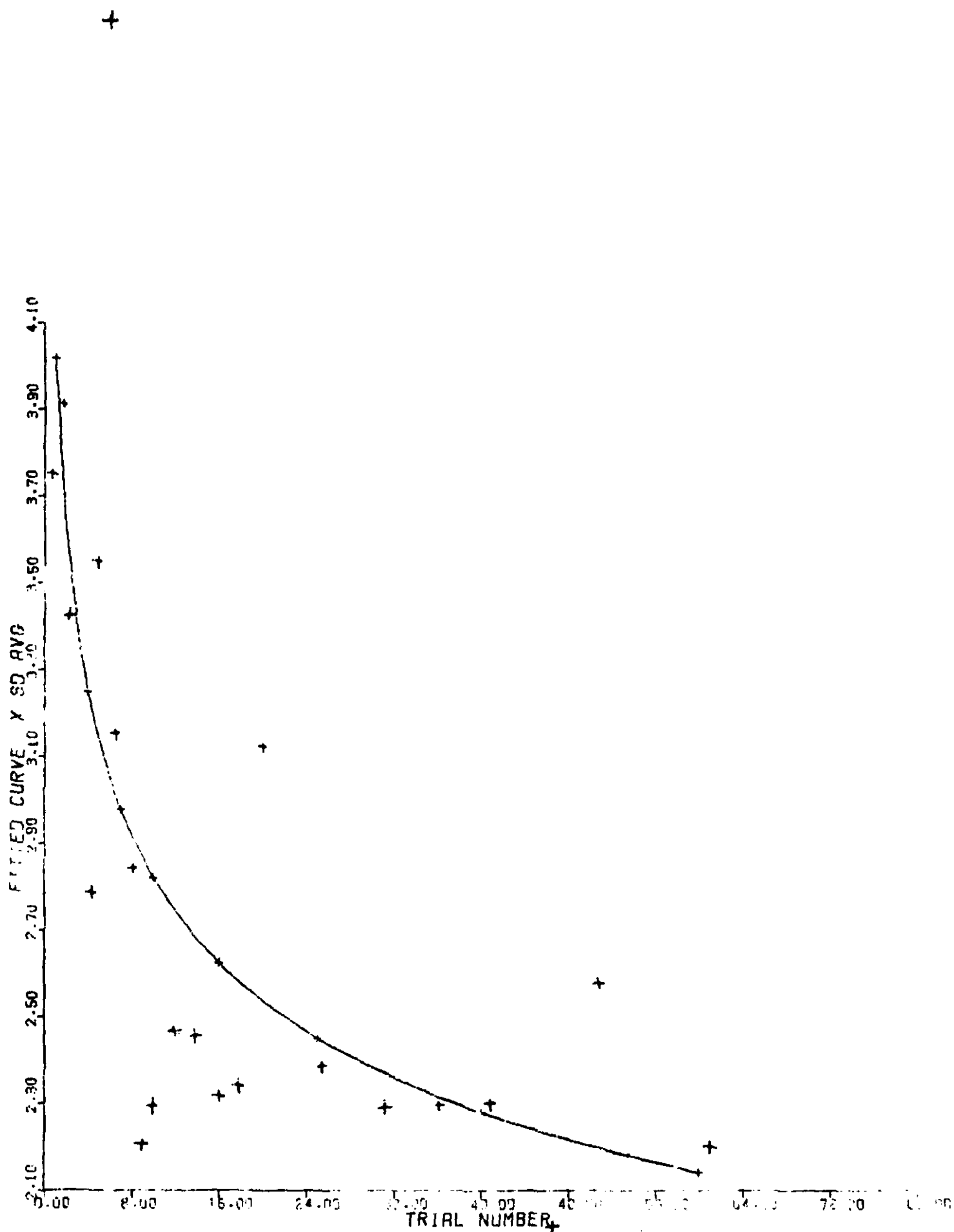


Figure D-25. Fitted Learning Curve X Standard Deviation

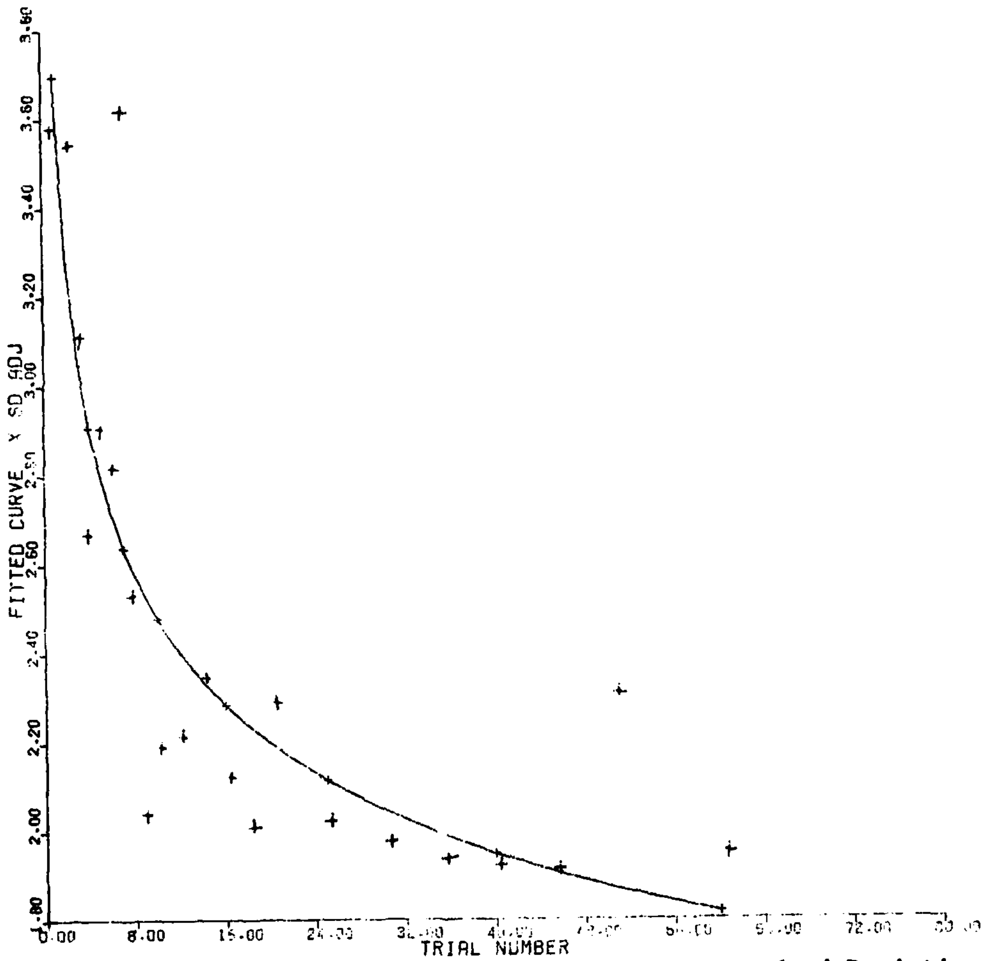
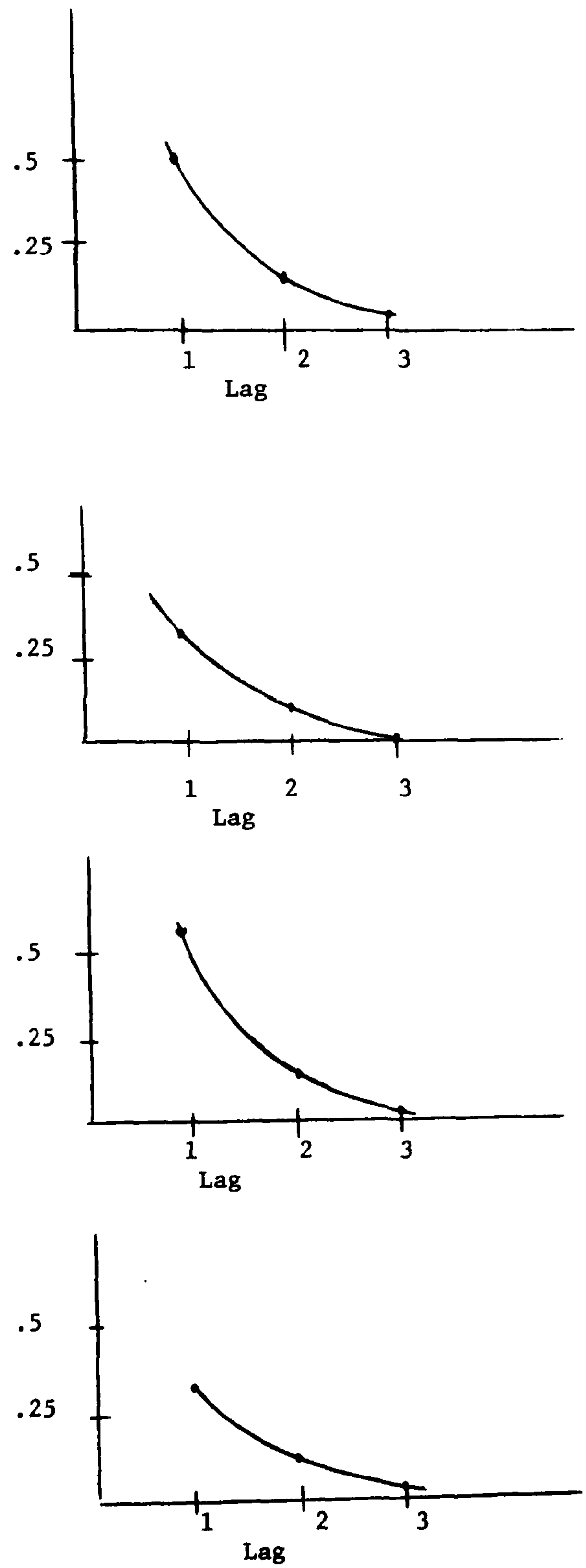


Figure D-26. Fitted Learning Curve X Adjusted Standard Deviation

APPENDIX E

APPENDIX E

Sample Decay Lag 1 to Lag 3
4 runs



APPENDIX F

APPENDIX F

THE AR(1) MODEL

The AR(1) model takes into account autoregression or the relation between a value and the preceding value. In the case of this tracking project the lag 1 model which was fitted shows that the error at time t is dependent upon the tracker's perception of his error at time t.

The variance of the AR(1) process is

$$K = \phi_1^K \frac{\sigma_\varepsilon^2}{1 - \phi_1^2} \qquad K = 0, 1, \ldots$$

$$E^2 = \frac{\gamma K(1-\phi_1^2)}{\phi_1^K}$$

For Lag 1 $\quad K = t-1 \quad K=0$

γ_o = unadjusted variance of the data

σ_ε^2 = variance free from autocorrelation at Lag 1

ϕ_1^0 = 1

ϕ_1 = Least Squares Estimator of the autoregressive parameter

$$\phi = (Z'Z)^{-1} Z'X$$

$$Z'Z = \begin{bmatrix} N-1 & \sum_{t-2}^{N-1} Xt \\ \sum_{t-2}^{N-1} Xt & \sum_{t-2}^{N-1} Xt^2 \end{bmatrix}$$

$$Z'X = \begin{bmatrix} \sum_{t=2}^{N} Xt \\ \sum_{t=2}^{N} XtXt-1 \end{bmatrix}$$

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