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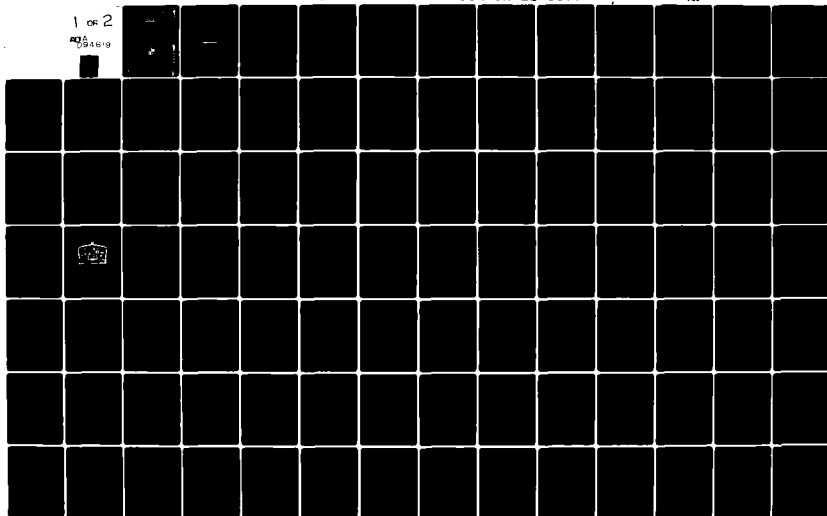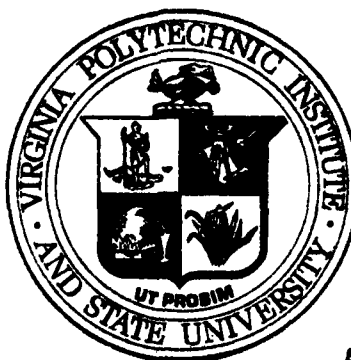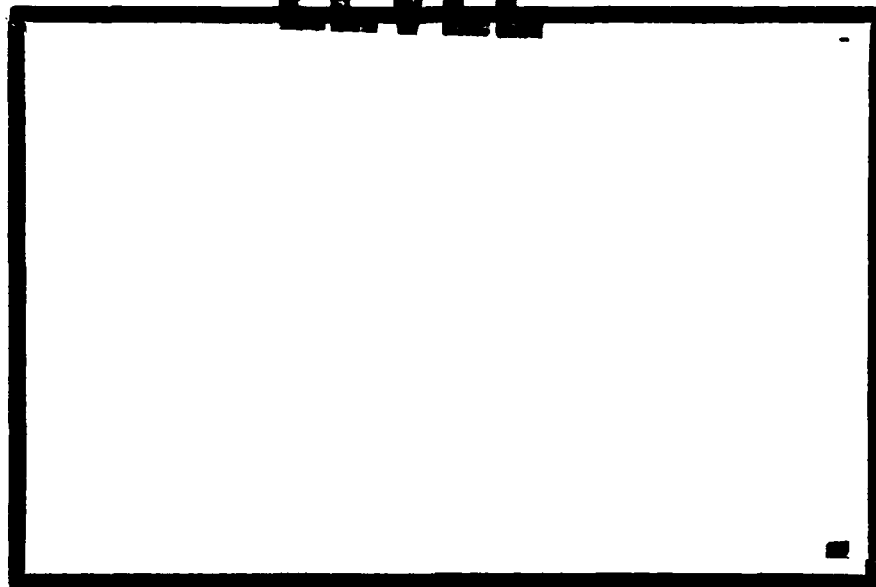UNCLASSIFIED   VPI-HFL-80-4-/AFOSR-80-1   AFOSR-TR-81-0077   NL

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AUTOMATED MOTOR SKILLS TRAINING OPTIMIZED
FOR INDIVIDUAL DIFFERENCES.

1 October 1976 - 30 September 1980

FINAL TECHNICAL REPORT.

by

Beverly H. Williges and Robert C. Williges

HFL-80-4/AFOSR-80-1

November 1930

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Prepared for
Life Sciences Directorate
Air Force Office of Scientific Research

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This report summarizes a four-year research effort directed toward the implications of using both microadaption and macroadaption in individualizing motor skills training. A general review of the research effort as well as a specific discussion of the research conducted during 1 October 1979 to 30 September 1980 is provided. Overall conclusions on the efficacy of micro versus macromodels of motor skills training are provided.

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STATEMENT OF WORK

Flying an airplane is a complex task requiring among other things skilled perceptual-motor performance. The acquisition of the necessary manual control skills for piloting involves considerable instructor and student time as well as expensive training equipment--either actual aircraft or sophisticated flight trainers. As early as 1954 Townsend and Flexman recognized that the effectiveness of simulator training depends not only on the training equipment used, but perhaps more critically on the training program incorporated. In other words, obtaining maximum transfer from a simulator may be as much a function of the way the simulator is used for training as it is a function of the degree and fidelity of simulation. In addition to providing a high degree of realism the engineering sophistication of today's high fidelity simulators allows for the automatic measurement of the trainee's performance and selection of the appropriate training scenario for each student. Caro (1973) concluded that the development of an appropriate training program is essential to realizing the full potential of these computer-based trainers.

As the fuel situation worsens, the Air Force will have a more compelling need to maximize the effectiveness of computer-based synthetic flight training. The training of motor skills continues to be a critical element in flight training because many of the new tasks pilots may be called upon to perform in future warfare involve high level motor skills. Such tasks might include low-level fast bomber weapons presentation, high-

speed, accurate firing of air-to-air and air-to-ground missiles, evasion of enemy missiles, and formation flying. By optimizing the use of synthetic trainers for the original learning, retention, and transfer of these critical motor skills, Air Force personnel should be better equipped to perform these all-important tasks.

A critical aspect in computer-based synthetic flight training is how to implement the trainer as a computer-controlled training program which is used most effectively and efficiently by the wide variety of students who use the simulator. Because each student is somewhat unique in terms of experience, rate of learning, approach to the training environment, and learning and control styles, a single predetermined training program is not always optimum for each individual.

In motor skills training one consistent result is the large intersubject variability in training time or final skill level resulting when only one fixed training procedure is employed. Modern computer technology provides the capability to process large amounts of continually varying data permitting the instructional environment to be adapted to the learning characteristics of the individual student. By using the computer inherent in the design of synthetic flight trainers, one should be able to develop effective ground-based training programs for individual students in pilot training with a subsequent reduction in the variability in rate of learning and/or post-training skill levels. The key element is the

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development of training models or algorithms that the computer can use to manipulate the training environment for each student.

Two general approaches to individualizing motor skills training can be taken. The first assumes that each student follows his or her unique learning model (micromodel) through training. Therefore, the training situation must be flexible to adjust to each student's unique training model. One example of a micromodel approach to individualized instruction is adaptive training. The use of the term adaptive training in motor skills development usually refers to a motor learning task in which the difficulty or complexity of the training task varies directly as a function of student performance. If the student's performance is within a specific error tolerance, the task difficulty or complexity increases automatically until an exit criterion is reached. If, on the other hand, the trainee is outside a specified error tolerance, the task difficulty is decreased. Kelley (1969) summarized the key elements in an adaptive training system: a continuous measure of trainee performance, one or more adaptive variables that can change the task difficulty or complexity, and a logic system for automatically changing the adaptive variable(s).

The second approach to individualizing training assumes that only a limited number of learner types exist. Students are categorized on various dimensions as to learner type and assigned to the optimal training alternative (macromodel). The macromodel approach has been explored by Cronbach and his

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colleagues (Cronbach and Snow, 1977) as it applies to cognitive skills development. One difficulty in Cronbach's approach is the need to specify underlying aptitude-treatment interactions in advance. An alternative macromodel approach investigated in the present research uses regression equations to predict individual training outcomes and uses these predicted outcomes to assign students to training conditions. Obviously the latter approach also assumes the existence of aptitude-treatment interactions, primarily in training situations with large inter-student performance variability, but these need not be specified. The emphasis is on developing prediction equations for each training type that predict a significant portion of variance and that differ in beta weights and/or predictors.

Before precise statements could be made about the utility and limitations of using micromodel and macromodel approaches for individualizing motor learning tasks, fundamental investigations of critical variables were necessary. A paper by Williges and Williges (1973) summarized some of the research issues germane to the problem area. To minimize the overall cost of this research, laboratory investigations were performed to reduce the number of training alternatives requiring subsequent field testing.

Microadaption

Automatic linear optimization. Much research has been directed toward the development of optimization models to

disseminate information in cognitive training. The goals of these within-task adaption procedures are: (1) to minimize training time and instructional costs, (2) to reduce variability in training time, and (3) to maximize student achievement by adjusting the instructional environment to individual, and perhaps changing, instructional needs. Various quantitative models have been explored for cognitive training including memory, artificial intelligence, automation, and regression models. Some optimization models use the cumulative history of all students who have taken the course as well as the response history and abilities of the individual student currently been taught.

In motor skills training the linear adaptive model developed by Kelley (1969) has been the stimulus for a great deal of research. In Kelley's system some aspect of student performance (system output) is measured and used in closed-loop fashion to set the level of the training problem (system input). If a student's performance is within a specific error tolerance, the task difficulty or complexity increases until the exit criterion is reached. If, on the other hand, student performance is outside a specific error tolerance, the task difficulty or complexity is decreased. The basic assumption of this model is that by adapting training to student performance the task is never too easy or too difficult for the student, much like the training provided by a skilled instructor.

Several preliminary applications of adaptive training to complex synthetic flight trainers have been attempted (Lowes,

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Ellis, Norman, and Matheny, 1968; Caro, 1969; Brown, Waag, and Eddowes, 1975). In addition, Rigney, Morrison, Williams, and Towne (1973) successfully used an adaptive model to train radar intercept operators. However, not all research on adaptive training has found it to be advantageous (see review by Williges and Williges, 1973). In an attempt to resolve some of these conflicts, the present research was directed toward basic issues in the application of adaptive training to motor skills.

Learner-controlled optimization. The antithesis of the computer-controlled adaptive model is learner-controlled instruction in which lesson strategy and sequencing is controlled by the student directly. The learner-controlled model has two primary advantages: (1) it is economical to develop because elaborate software programs for selecting content or sequence are unnecessary; (2) students learn to evaluate their own performance. Adams (1971) contends that developing an internal feedback model to evaluate one's performance is an essential element in motor learning. Recently learner-controlled instruction has received a great deal of attention and has been used more frequently. For example, the TICCIT computer-based instructional system (MITRE Corporation, 1974) is primarily a learner-controlled training system. However, many research issues dealing with learner-controlled instruction remain unanswered.

Research on learner-controlled instruction for cognitive skills provides some support for the approach (Lahey and Crawford, 1976; Fredericks, 1976; Mager and Clark, 1963). In a

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review of research on learner control in computer-assisted instruction, Judd, O'Neil, and Spelt (1974) characterized the early research as supportive of learner control and the later research as being conflicting. They also noted that positive results are most often obtained with highly motivated and/or intelligent students.

Williges and Williges (1977) conducted the first research on learner-controlled instruction in motor learning. Students used either fixed-difficulty, adaptive, or learner-controlled strategies to learn a two-dimensional pursuit tracking task. No reliable differences in training time were noted, but students trained using learner-controlled procedures had less tracking error ($p<.05$) in the 7-minute transfer task. These results support the notion that the student is quite capable of effectively manipulating the learning situation based on his own internal training model.

One disadvantage of the learner-controlled model is that the complexity of the students' decisions increases as the complexity of the training situation increases. For example, in the Williges and Williges study (1977), students had only three possible inputs--increase task difficulty, decrease task difficulty, or keep task difficulty the same. If the difficulty of each axis in the task were manipulated separately, the students would have had six possible inputs. Obviously at some point the number and complexity of decisions required become prohibitive, especially when they must be made concurrent with performing a continuous motor task.

One could argue that learner-controlled instruction fared well in the Williges and Williges (1977) study only because the computer model used in the automatic adaption condition was suboptimal for the task to be learned. Even if this is the case, learner-controlled instruction deserves consideration as a viable individualized training approach at least until more appropriate computer optimization models are developed and evaluated.

Macroadaption

Pretraining assignment to training types based on individual student differences involves the measurement of learner characteristics that have an effect on learning and the application of these measures to the selection of an appropriate training strategy for each student. The role of the computer here is as a manager of instruction. Using cognitive tasks, researchers such as Pask (1976) have demonstrated that when the student's preferred learning style and the teaching strategy employed are mismatched learning is severely disrupted in terms of comprehension and retention.

Instructional theorists have also noted the importance of learning style. Carroll's (1963) theory suggests that the degree of learning a given task is a function of the amount of time spent learning the task in relation to the amount of time needed to learn the task. Time needed is based upon learning under optimal conditions where optimal conditions are defined by the student's learning style preference. Bloom (1976)

provides three categories of predictors of time to learn: (1) cognitive entry behaviors (prior experience with the task), (2) affective entry behaviors (motivation level of the student), and (3) quality of instruction (appropriateness for the student).

As a manager of instruction the computer uses a model to determine a priori the appropriateness of a particular training method. For this purpose, regression models might be useful to predict training success. Kaskowitz and Suppes (1973) have suggested that a regression equation may be considered to be a mathematical model in the sense that a linear relationship between rate of learning and certain independent variables is hypothesized.

Two findings reported by Wagner, Behringer, and Pattie (1973) provided the impetus for the present research in which regression equations were used to predict optimal training group assignment. Using regression equations to predict time to complete a course on stock control and accounting, Wagner et al. found that (1) simple mathematical equations were the best predictors of performance and (2) grouping students according to mode of instruction (audio-visual or programmed instruction) and using separate equations improved prediction. The improvement in prediction when students are grouped by training type suggests that training type interacted with individual differences among students. If so, the best predicted score might be useful to select an optimal training assignment.

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A preliminary evaluation of the use of multiple regression for training group assignment has been conducted using the Air Force Advanced Instructional System's Inventory Management course. McCombs (1979) reported modest savings in training time when regression models were used to select students for alternative training modules. However, because the study was conducted within the constraints of an operational training system, several limitations should be noted. First, alternative treatments were available only in selected lessons (27% of the course). Second, no students were purposefully mismatched, so the discriminability of the selection procedure could not be tested. Third, selection of the optimal training type could be overridden when the instructional materials were not available or when an instructor changed a student's assignment. However, even with these limitations, consistent savings in time to learn a cognitive task were obtained using regression modeling. The present research program extended the regression model approach to the perceptual-motor domain.

STATUS OF THE RESEARCH

Task Development

During the first six months of this research program much
of the effort was devoted to the development and implementation
of a multiparameter flexible computer program for generating a
tracking task. The task was similar to the one used by
Williges and Williges (1977) as shown in Figure 1. A Digital
Equipment Corporation PDP 11/10 or 11/55 computer, a Textronix
4014-1 graphics display, a Measurement Systems Model 435 two-
axis isometric controller, and associated hardware computer
interfaces were combined to generate a two-dimensional pursuit
tracking task. The hardware configuration for the two-
dimensional pursuit tracking task is given in Figure 2.

After initialization of the task parameter values by the
experimenter, the task was presented to the subject on the
Tektronix display. To vary task difficulty during the task
various parameters could be manipulated automatically through
computer logic or student input, manipulated based on a
preprogrammed schedule of changes, or maintained at a fixed
level of difficulty. Three independent, random, band-limited
functions were used to determine the forcing function of the
pursuit symbol (X) on the display. The three functions
determined the length of movement in each axis and the duration
of the vector movement. The forcing function of the tracking
symbol (0) was generated from the output of the control stick.
The pushbutton keypad permitted the subject to raise or lower
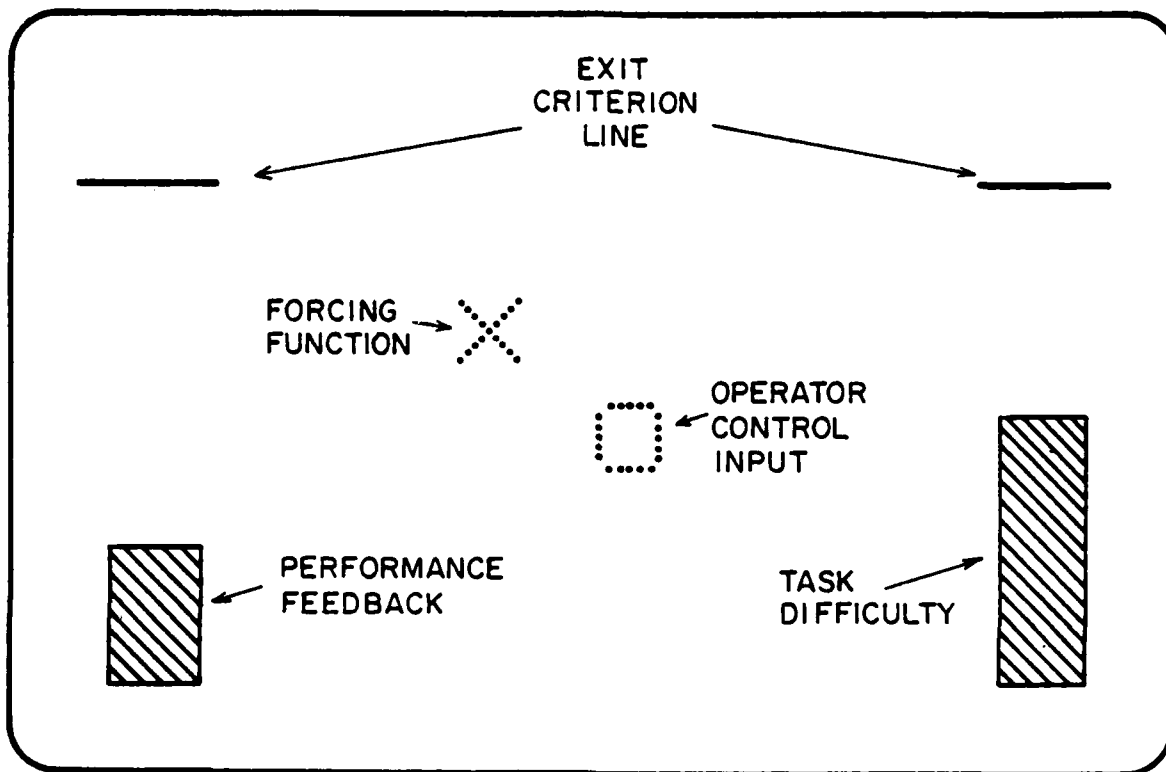
Figure 1. Two-dimensional pursuit tracking task with feedback bars.

SUBJECT

CONTROL STICK

GRAPHICS
DISPLAY

A/D

REAL-TIME
CLOCK

DISK

MINICOMPUTER

PROGRAMMABLE
REAL-TIME
CLOCK

TAPE

KEYBOARD

CONSOLE
SCREEN

SWITCH

EXPERIMENTER
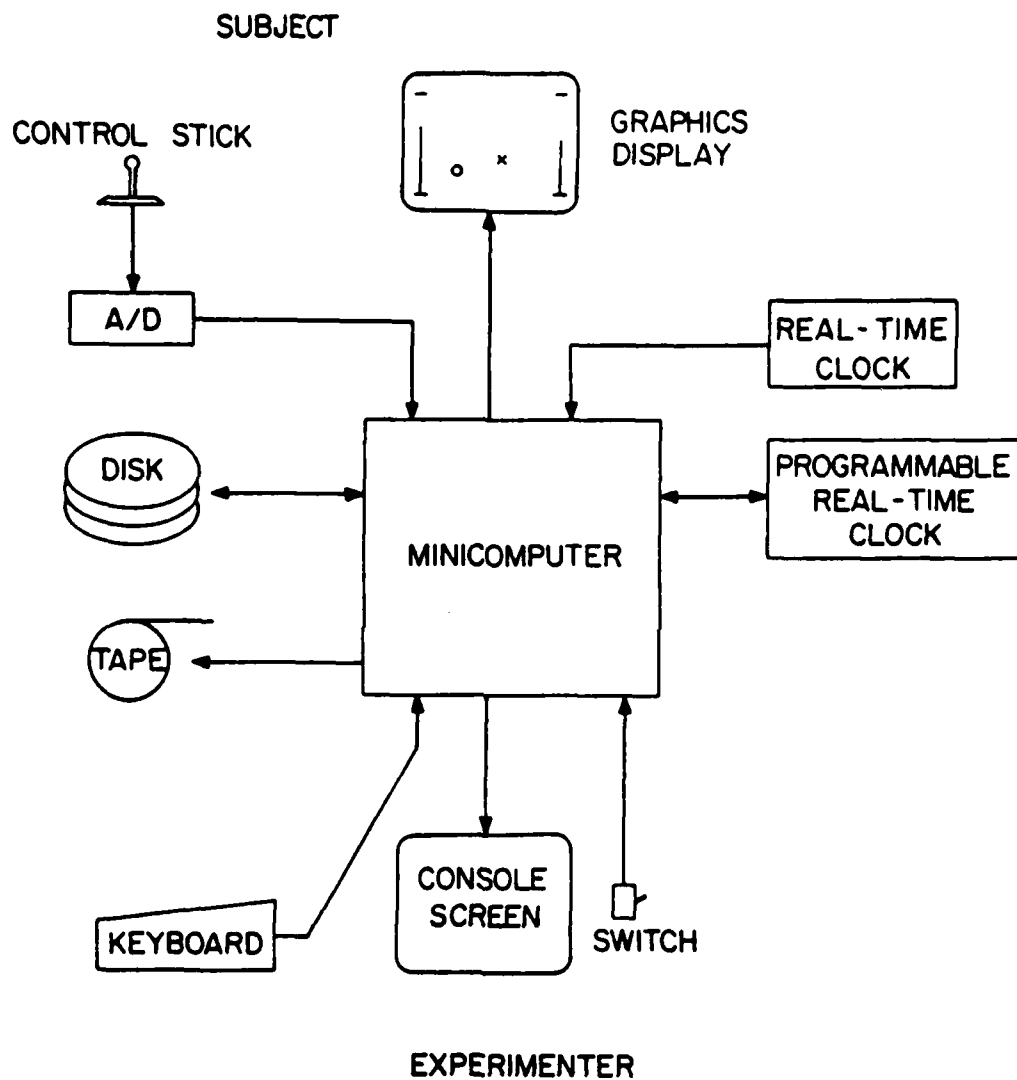
Figure 2. Hardware configuration for the two-dimensional
pursuit tracking task.

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task difficulty in the learner-controlled training condition. The programmable clock assured a uniform sampling rate of the joystick and pushbutton outputs and calculated the subsequent graphic updates. The timing of the refresh cycle of the dynamic images on the display was controlled by the real-time clock. The real-time clock was also used to time the 3-minute training periods and 1-minute rest periods. When termination of the experimental session was warranted, the experimenter was able to halt program execution by setting a switch on the front panel of the minicomputer.

System Dynamics

The following transfer function describes the system dynamics in each axis:

$$\theta_{ox}(S) = (1-\alpha) K_1 \frac{\theta_{ix}}{S} + \alpha K_1 K_2 \frac{\theta_{ix}}{S^2}$$

where:

$\theta_{ox}(S)$ = the Laplace transform of the scalar change in position of the "O" in one axis

α = a weighting constant used to weight rate control and acceleration control on a relative basis

K_1 = gain constant

K_2 = time constant

θ_{ix} = input force on the control stick in one axis

S = the Laplace transform independent variable.

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The random movement of the pursuit symbol was generated by
simulating a computer-operated control stick identical to the
transfer function of the isometric controller as described in
Equation 1. The K_1 constants for the pursuit symbol were
derived as a function of the maximum and minimum velocities of
the "X" set by the experimenter-defined parameters of the task
and the effective tracking area defined for the display. The
value for the input force in newtons was chosen from a random
number generator internal to the minicomputer used to generate
the experimental task. Task difficulty was defined in terms of
the movement speed of the pursuit symbol and changed relative
to the output value of the simulated control stick.

Exit Criterion

Exit criterion was determined both by task difficulty and
accuracy of tracking. The criterion level of task difficulty
during training was the maximum possible movement speed of the
"X" as defined by the experimenter. Tracking accuracy was
measured by the distance between the "O" and the "X".
Criterion error tolerance was 10% of the effective screen
diagonal. Training was terminated when both conditions were
met for a period of 20 continuous seconds.

Training Types

Three training alternatives were investigated: computer-
adapted training, learner-adapted training, and fixed-
difficulty training. Task configurations for each are given
below.

Computer-adapted training. A small-step adaptive logic
was available to vary task difficulty automatically by changing
the maximum allowable output value of the simulated control
stick. Absolute vector tracking error was computed every 60
ms. A sliding average error was compared to a tolerance limit
of 10% of the screen diagonal to determine when adjustments in
task difficulty were necessary. With such a small-step
adaptive logic, performance could be stabilized throughout
training, but changes in task difficulty were not readily
apparent to the student from the task itself.

Learner-adapted training. In the learner-controlled
training situation students were able to increase or decrease
task difficulty by means of a pushbutton keypad. Strategies
for incrementing or decrementing task difficulty were left
completely up to the student.

Fixed-difficulty training. In the fixed-difficulty
training condition, task difficulty was maintained at the
criterion level throughout training. Determining attainment of
the exit criterion was based solely on the measurement of
tracking error between the control output symbol and the
pursuit symbol.

Transfer Task

After training to criterion and a 5-minute rest period,
all subjects were given a 6-minute transfer task identical with
the training task with the exceptions that no feedback was
given and task difficulty shifted among three levels without
regard to the student's level of performance.

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Feedback

Visual feedback was provided as shown in Figure 1. On the left hand side of the display a bar graph labeled "ACCURACY" appeared. Whenever the "O" was within the error tolerance for accuracy, this vertical bar disappeared from the display. On the right hand side of the display a bar graph labeled "DIFFICULTY" appeared. Task difficulty variations were reflected in changes in this bar graph. Whenever task difficulty was at the criterion level, this bar disappeared. (In the fixed-difficulty training condition this bar was never displayed.)

Auditory feedback could be provided through a Utah loudspeaker, voltage control amplifier, analog adder, and counter. Task difficulty was indicted by 50 ms "beeps" at 400 Hz and 46 dB. When the task was at its lowest level of difficulty, the beeps were presented at a rate of 20 per second and were perceived as a continuous tone. At the criterion level of task difficulty the tone was no longer presented. Tracking accuracy was indicated by a continuous, 2,000 Hz tone varying in amplitude from 46 dB to 51 dB. Whenever the tracking symbol was outside the error tolerance for accuracy, onset of the accuracy tone occurred at 46 dB increasing in amplitude to 51 dB as error approached 50% of the effective screen diagonal. All frequencies and amplitudes for the two tones were selected such that no masking occurred.

Microadaption

Feedback in Adaptive Training

Despite the general agreement among learning theorists that feedback is critical for motor skill acquisition, the Kelley (1969) adaptive logic system minimizes the usefulness of _intrinsic_ task feedback. By manipulating task difficulty based on performance, a relatively constant level of error is maintained over time. Consequently, the student sees little or no progress in terms of error. Kelley was not unaware of this potential limitation of his adaptive training model and recommended that it could be overcome by providing augmented feedback in terms of a meter indicating exact level of task difficulty and perhaps an indicator of out-of-tolerance conditions in complex tasks. Eventually augmented feedback must be removed in order to transition to the real-world situation in which the student will have to rely on the intrinsic feedback in the task. However, Kelley provided no data to suggest the optimum type and form of augmented feedback to provide during training nor any data to suggest what happens when augmented feedback is withdrawn at various stages during adaptive training or during transfer.

Three studies were performed to examine the need for augmented feedback in adaptive training. Two studies dealt only with visual feedback, while a third study dealt with visual and auditory feedback.

Study I.   In Study I 24 subjects randomly assigned to one
of four treatment combinations (Table 1) were trained
adaptively.   The purpose of the study was to compare various
combinations of feedback and no feedback in training and
transfer.   No differences in training time-to-exit or transfer
performance due to feedback condition were exhibited (p>.05).
However, during post-experiment interviews several subjects
indicated that they had attempted to use the augmented
feedback, but their tracking performance declined sharpely so
they abandoned it.

Study II.   In Study II the effects of augmented visual
feedback on adaptive or fixed-difficulty training were
compared.   Twenty-four male subjects were randomly assigned to
one of four training conditions: adaptive/feedback,
adaptive/no feedback, fixed-difficulty/feedback, fixed-
difficulty/no feedback.   In all cases no augmented feedback was
provided in transfer.   Results of the analyses of variance
indicated no differences in training time-to-exit (p>0.10).
Thus, visually presented augmented feedback did not aid
subjects in either type of training procedure.   Furthermore,
subjects trained adaptively required the same amount of
training as those in the fixed-difficulty conditions.   The
presence or absence of visual feedback in training did not
prove to have any effect on transfer performance (p>0.10).
However, subjects who were trained adaptively performed
reliably better in transfer than those receiving fixed-
difficulty training, $\underline{F}(1,20)=9.24$, $\underline{p}=0.0065$.

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TABLE 1

Treatment Combinations in Feedback Study I

Condition	Training	Transfer
I	Feedback	Feedback
II	Feedback	No Feedback
III	No Feedback	Feedback
IV	No Feedback	No Feedback

The results of the first two studies imply that continually varying visual feedback produces neither a performance nor a learning effect in a complex, closed-loop tracking task. However, based on the conclusions from open-loop motor skills research, it would appear that augmented feedback should have enhanced performance in training and transfer. From the comments of subjects there was reason to believe that the motor task imposed such a large visual workload that subjects were unable to use the visual feedback effectively. Therefore, it may be necessary to present feedback in a different mode when a high visual workload exists.

Study III. To examine the relative benefits of auditory and visual augmented feedback 96 male subjects were assigned to one of four feedback conditions: (1) auditory feedback, (2) visual feedback, (3) auditory and visual feedback, and (4) no augmented feedback. Two types of training were examined: fixed-difficulty and computer adaptive. No reliable effects due to feedback or training procedure were noted in the

training time-to-exit data. However, subjects trained adaptively performed significantly better ($p<.05$) in transfer than those subjects trained in the fixed-difficulty situation.

The results of all three studies suggest that augmented feedback does not enhance training in a closed-loop adaptive training system with clearly discernable intrinsic task feedback. However, task-difficulty feedback may be useful to maintain a steady increase in performance over very lengthy training periods, and off-track feedback may be effective in enhancing performance in adaptive systems lacking clearly discernible intrinsic feedback.

Learner-Controlled Training

A preliminary study by Williges and Williges (1977) ascertained that learner-controlled instruction can be as effective as computer-optimized training and more effective than fixed-difficulty training. In this study no differences in time-to-train were obtained, but the learner-controlled training produced more accurate tracking in the transfer task than the fixed-difficulty training ($p<.05$).

A second study completed during this contract year reexamined the effectiveness of learner-controlled training. A total of 90 subjects were randomly assigned to one of three training conditions: fixed-difficulty, computer-adapted, and learner-controlled. An equal number of male and female subjects received each type of training. This study differed from the prior study on learner-controlled training in several

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respects. First, a more difficult tracking task was used (pure acceleration control). Second, in order to approximate a realistic training situation more closely, no effort was made in the second study to equalize workload by requiring the student's in all conditions to use the task difficulty change buttons; only students in the learner-controlled condition used the buttons. (In the first study all student's were told that their button responses were being recorded in order to evaluate their preferred levels of task difficulty throughout the training session.) These differences in the two studies may account for the divergent findings. In the present study students trained in the fixed-difficulty or computer-adapted conditions performed more accurately in the transfer task than those students in the learner-controlled condition. It is quite likely that the requirement for students to make decisions concerning changes in the training situation interferes with effective training by unnecessarily increasing their workload. Time-to-train results were in agreement with many of the studies in this series in which individualized training procedures resulted in increased training time ($p<.05$). It should be pointed out that in neither study was any effort made to select students for which the learner-controlled situation would be more appropriate. Learner control may be differentially effective for various types of students. Factors, such as inquisitiveness, sex of student, and prior experience with the task may be important predictors of the effectiveness of learner-controlled instruction. By

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carefully selecting students for the learner-controlled
condition, one might observe an advantage for learner-
controlled training. However, without such pretask selection
and in the absence of artificial workload adjustments, the
learner-controlled condition seems to suffer from the increased
workload imposed on the student.

Conclusions on Microadaption

Some trends emerge when the results of all the studies
examining microadaption techniques for individualized training
are compared to traditional fixed-difficulty training. A
summary of training time (time-to-exit in minutes) is given in
Table 2, and a summary of the transfer analyses (tracking error
as a percent of scale) are given in Table 3. Several
conclusions are noteworthy:

(1) Both of the individualized training procedures
(computer-adapted or learner-controlled) resulted in
additional training time, when any difference among
training types was obtained.

(2) If any difference in transfer performance was
measured, better performance resulted from the computer-
adapted training procedure.

(3) Although microadaption procedures for
individualized training may yield some improvement in
transfer performance, this is not without risking an
increase in training time.

(4) Without a clear cut advantage for the individualized microadaption procedure, the additional cost required for development does not appear to be justified.

(5) In all studies reliable sex differences were obtained both in time-to-train and in transfer tracking accuracy. The individualized training procedures did not eliminate or reduce these differences.

TABLE 2

Summary of Training Time-to-Exit Results

Study	Training Type	Number of Subjects	Training Time (minutes)	p
1	Fixed	28	19.3	.0599
	Adaptive	30	24.8	
2	Fixed	20	12.7	.0157
	Adaptive	18	20.9	
3	Fixed	60	15.6	.2464
	Adaptive	60	17.5	
4	Fixed	12	20.7	.8422
	Adaptive	12	20.9	
5	Fixed	48	14.2	.4776
	Adaptive	48	15.4	
6	Fixed	30	15.8	.0307
	Adaptive	30	21.9	
	LC	30	21.4	

TABLE 3

Summary of Transfer Task Tracking Accuracy (Percent of Scale)

Study	Training Type	Number of Subjects	Tracking Error (%)	p
1	Fixed	28	10.9	.9039
	Adaptive	30	10.8	
2	Fixed	20	11.6	.1563
	Adaptive	18	10.6	
3	Fixed	60	11.6	.1008
	Adaptive	60	10.8	
4	Fixed	12	14.1	.0065
	Adaptive	12	12.4	
5	Fixed	48	9.8	.0251
	Adaptive	48	9.0	
6	Fixed	30	10.5	.0345
	Adaptive	30	10.3	
	LC	30	11.9	

Macroadaption

Despite the fact that skill training is usually an individual rather than a group experience, research to evaluate training approaches has generally employed group statistics in which a fixed population is assumed and the training alternative producing the highest mean performance is sought. Another approach emphasizes selection where a fixed training type is assumed, and the aptitude that maximizes the slope of the function relating training outcome to measured aptitude is sought (Cronbach and Gleser, 1965). Both of these approaches assume that there is clearly one optimal training strategy for all students provided the students are selected for training appropriately. Much experimental evidence would indicate that this is rarely true. Rather than fault the training technique or selection procedures, one might assume that aptitude-treatment interactions may exist in training situations where a large variability in student performance is observed. Some researchers have attempted to isolate these interactions. An alternative is to develop prediction models for each available training procedure and use students' predicted scores for training group assignment. The present research evaluated the validity of the prediction approach.

Three separate efforts to develop prediction equations for training group assignment were completed during this contract. Each addressed a separate issue. The first effort examined the effectiveness of regression models for selecting training group

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assignment. The second effort addressed the issue of whether or not the prediction models would change with different training environments and subject populations. The final effort extended the modeling to a third training alternative and examined whether the models would be sensitive to minor changes in the training task. A summary of each of these efforts is given below.

Evaluation of the Regression Model Approach

The initial effort required three studies, two to develop and validate regression models for time-to-exit from training on the tracking task and one to evaluate the efficacy of these models for assigning students to either a fixed-difficulty or computer-adapted training procedure.

A battery of six tests and sex of the student were used to provide predictor variables. The pretest battery included: (1) pursuit rotor (motor skill), (2) Embedded Figures Test (field independence), (3) Identical Pictures Test (perceptual speed), (4) Maze Tracing Test (spatial scanning), (5) Map Memory Test (visual memory), and (6) Cube Comparison Test (spatial orientation). The Embedded Figures Test is from the Educational Testing Service (Witkin, Altman, Raskin, and Karp, 1971), and the last four tests are paper-and-pencil tests from the Ekstrom, French, Harman, and Derman (1976) battery. Five stepwise regression procedures from the SAS statistical package (Barr, Goodnight, Sall, and Helwig, 1976; Barr, Goodnight, Sall, Blair, and Chilko, 1979) were used to determine

equations; those with the fewest predictors and accounting for the most variance were selected when different equations resulted from the various procedures. The five procedures included forward selection, backward elimination, stepwise, maximum R^2 improvement, and minimum R^2 improvement.

A double cross-validation procedure was used to validate the regression equations which predicted time to learn the two-dimensional pursuit tracking task (Kerlinger and Pedhazur, 1973). Because the coefficients of multiple determination were consistently high, the two samples were combined, and new equations were generated from the combined data. These combined sample equations, given in Table 4, were used in the third study for training assignment.

To evaluate the efficacy of the regression approach for training assignment multiple regression equations were used to assign 40 students to fixed-difficulty or adaptive training based upon the shorter predicted time-to-train score. An additional 40 students were randomly assigned to the two training conditions, and 40 students were purposefully mismatched to training by using the longer predicted time-to-train score.

Results of an analysis of variance on actual training time-to-exit scores revealed reliable main effects of assignment, $F(2,108)=17.27, p<.0001$, and sex, $F(1,108)= 40.57, p<0001$. Use of the regression approach reduced training time by almost 50% as compared to random assignment and even more when compared to students who were mismatched. Variance

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TABLE 4

Combined Sample, Raw Score Regression Equations for Time to Learn a Two-Dimensional Pursuit Tracking Task Using Fixed-Difficulty or Computer-Adapted Training

---

Fixed-Difficulty Training

$$TE_{FD} = -897.9 + 1.7*EF + 45.5*IP - 32.7*CC$$

$n = 48$
$R^2 = .632$
$R_S^2 = .607$

Computer-Adapted Training

$$TE_{CA} = 2641.7 + 1.7*EF - 256.9*MM + 516.4*SX$$

$n = 51$
$R^2 = .756$
$R_S^2 = .740$

SX = Sex of Student
CC = Cube Comparison
EF = Embedded Figures Test
IP = Identical Pictures Test
MM = Map Memory Test

in training time was reduced by approximately 40% by optimizing training group assignment. Table 5 summarizes the reliable effects from the analysis of training time.

The pie charts in Figure 3 graphically depict the reductions in average training time and variability in training time obtained by using two training alternatives with student matching versus providing only fixed-difficulty training. These data clearly demonstrate the advantage of regression models to optimize training group assignment. The optimization procedure not only resulted in savings in training time, but

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TABLE 5

Summary Statistics for Training Time-to-Exit (minutes) for the
Selection Study

Effect	Mean	σ
Training Type		
Fixed-Difficulty	15.6	10.1
Computer-Adaptive	17.5	12.4
Assignment Procedure		
Matched	10.0	7.0
Random	18.7	11.6
Mismatched	21.1	11.7
Sex of Student		
Male	11.4	7.1
Female	21.8	12.4

also reduced the variance among students which should certainly
be helpful in any military setting where training periods tend
to be time-constrained.

Joint VPI/Air Force Academy Research

The first set of regression equations had been developed
using civilian university students, both men and women. These
students are in the same age range and probably possess many
characteristics similar to young military officers. To
establish the validity of the regression models for what might
be a new subject population, a joint research project with the
Air Force Academy was undertaken. A set of pretests, including
the tests used to generate the original regression models, was

55.56

65.58

44.44

34.42
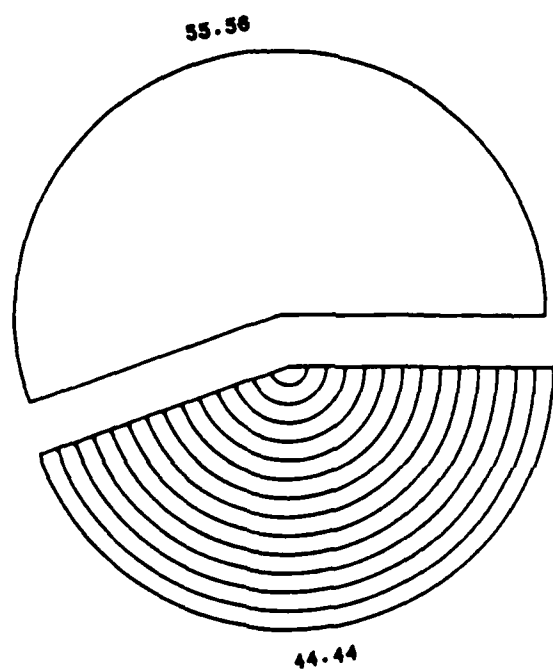
MEAN TRAINING TIME
SAVINGS WITH MATCHING
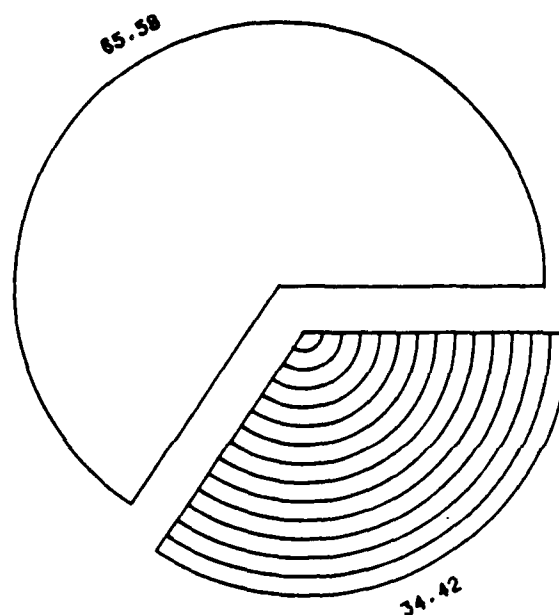
VARIABILITY IN TRAINING TIME
SAVINGS WITH MATCHING

Figure 3. Pie charts depicting savings in training time using the regression procedures for matching students to training type.

given to 100 VPI students and 100 Air Force Academy cadets. Half of each sample was female. Scores on these tests were used to generate new multiple regression prediction equations this time predicting post-training performance on a desk-top flight trainer. The purpose of the research was to examine the prediction equations obtained to determine if there were different equations for civilian university students versus Air Force Academy cadets or for male versus female students. Indirectly these comparisons might have implications for pilot selection and attrition.

All subjects were tested on the pretest battery developed at VPI which included the pursuit rotor and five information processing tests as previously described. The information processing tests used were comparable to the tests included in the Air Force Officer Qualifying Test (AFOQT) measuring perceptual characteristics. In addition, the two tests on the Psychomotor Test Device, Model 1017 (PTD) designed by the Systems Research Laboratory, Dayton, Ohio, were administered. These tests were under consideration by the Air Force as pilot selection devices and featured automatic testing and scoring procedures. The first test on the PTD is a two-hand coordination, pursuit tracking task. The display for Task 1 is given in Figure 4. The second test involved both a two-dimensional compensatory tracking task controlled by a dual-axis joystick and a one-dimensional compensatory tracking task controlled by foot pedals. The display for PTD Test 2 is given in Figure 5.
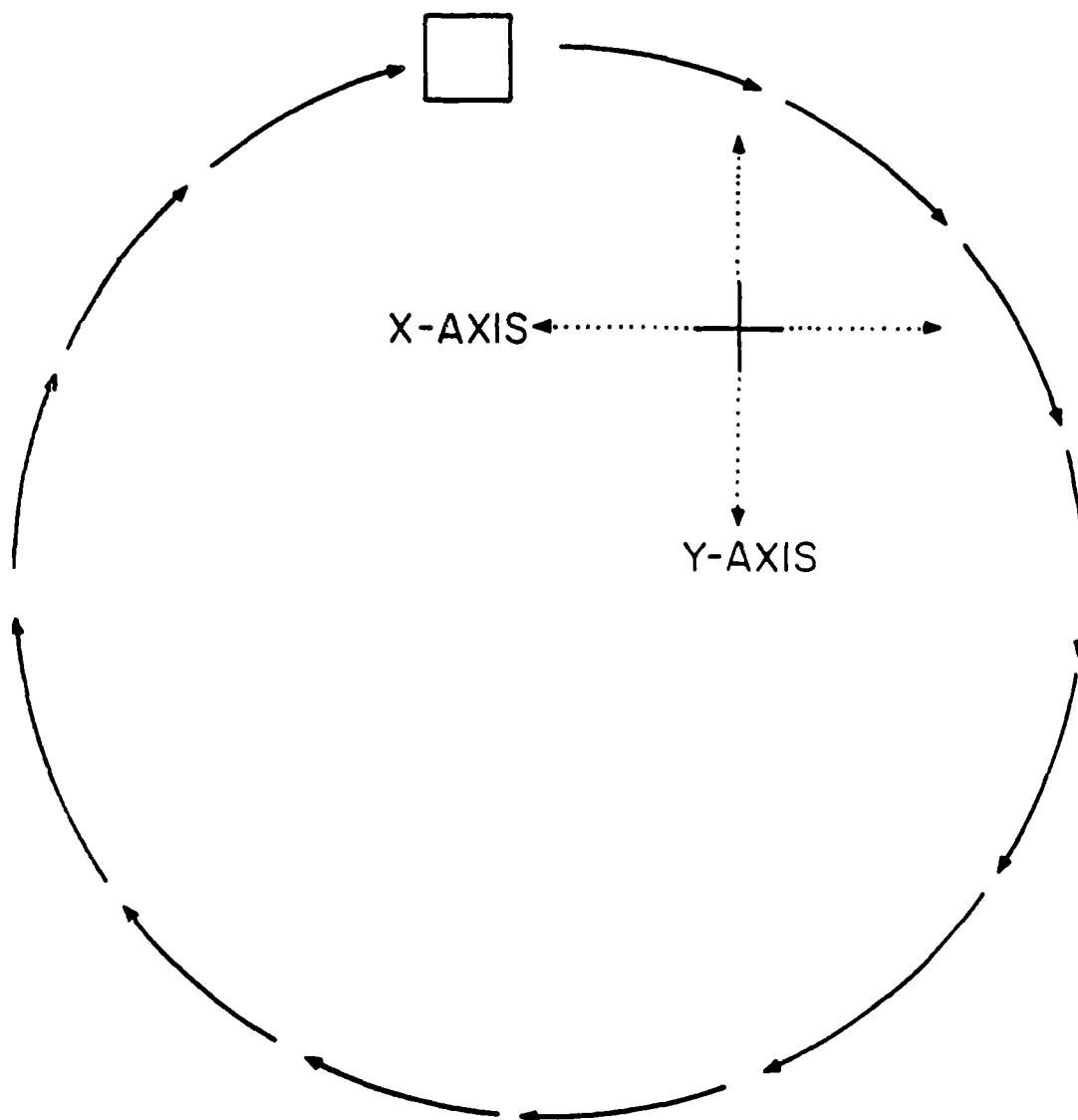
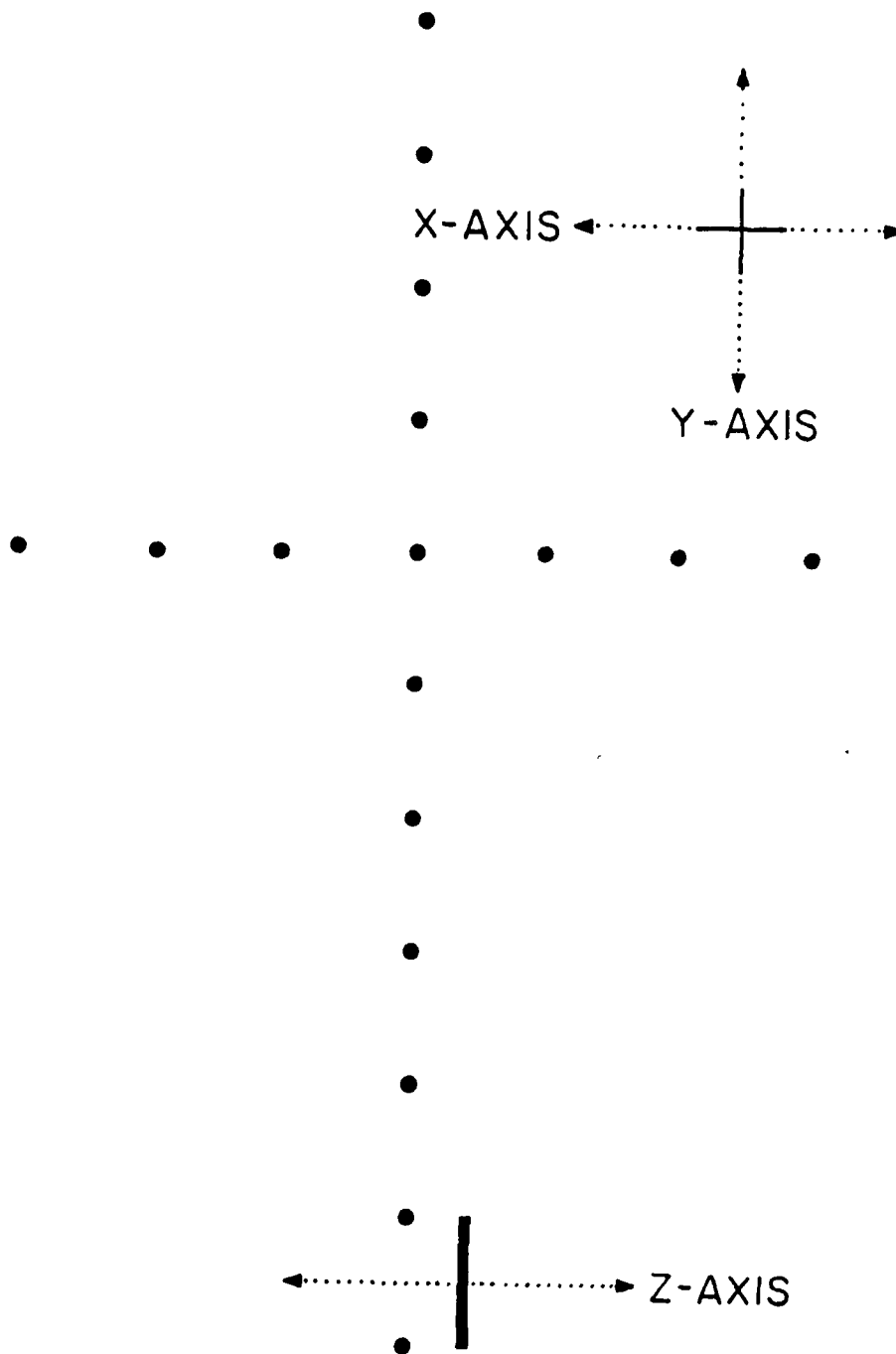Figure 4. Display for PTD Test 1.

Figure 5.   Display for PTD Test 2.

Scores from the pretests plus sex of student and institution were used to predict performance on four flight tasks performed on the ATC desk-top flight trainer equipped with the flight instruments normally associated with light aircraft. Figure 6 illustrates the instrument panel of this trainer. After training students were tested on four manuevers, once in smooth air and once in simulated air turbulence. The tasks were climb on a heading at a specified vertical velocity, cruise straight and level, descend at a specified vertical velocity on a given heading, and make a level standard rate turn of 130 degres.

Analyses of pretest battery scores indicated no reliable differences due to institution. However, females scored better than males on the Identical Pictures Test ($p=.01$), and males scored better than females on the Cube Comparison Test, ($p=.001$), Embedded Figures Test ($P=.0001$), and pursuit rotor tracking ($p=.0001$). On all PTD tasks males performed better than females ($p<.0001$), and Air Force cadets performed better than VPI undergraduates ($p<.02$).

The analysis of ATC flight test performance ratings revealed reliable main effects of sex, ($p<.0001$), and institution, ($p<.0009$), indicating that males performed better than females and VPI undergraduates performed better than Air Force cadets. The reliable interaction of sex and institution ($p<.0006$) indicated that Air Force Academy females performed significantly poorer than all other students tested. The poor showing, on the average, for the female cadets seems to be the
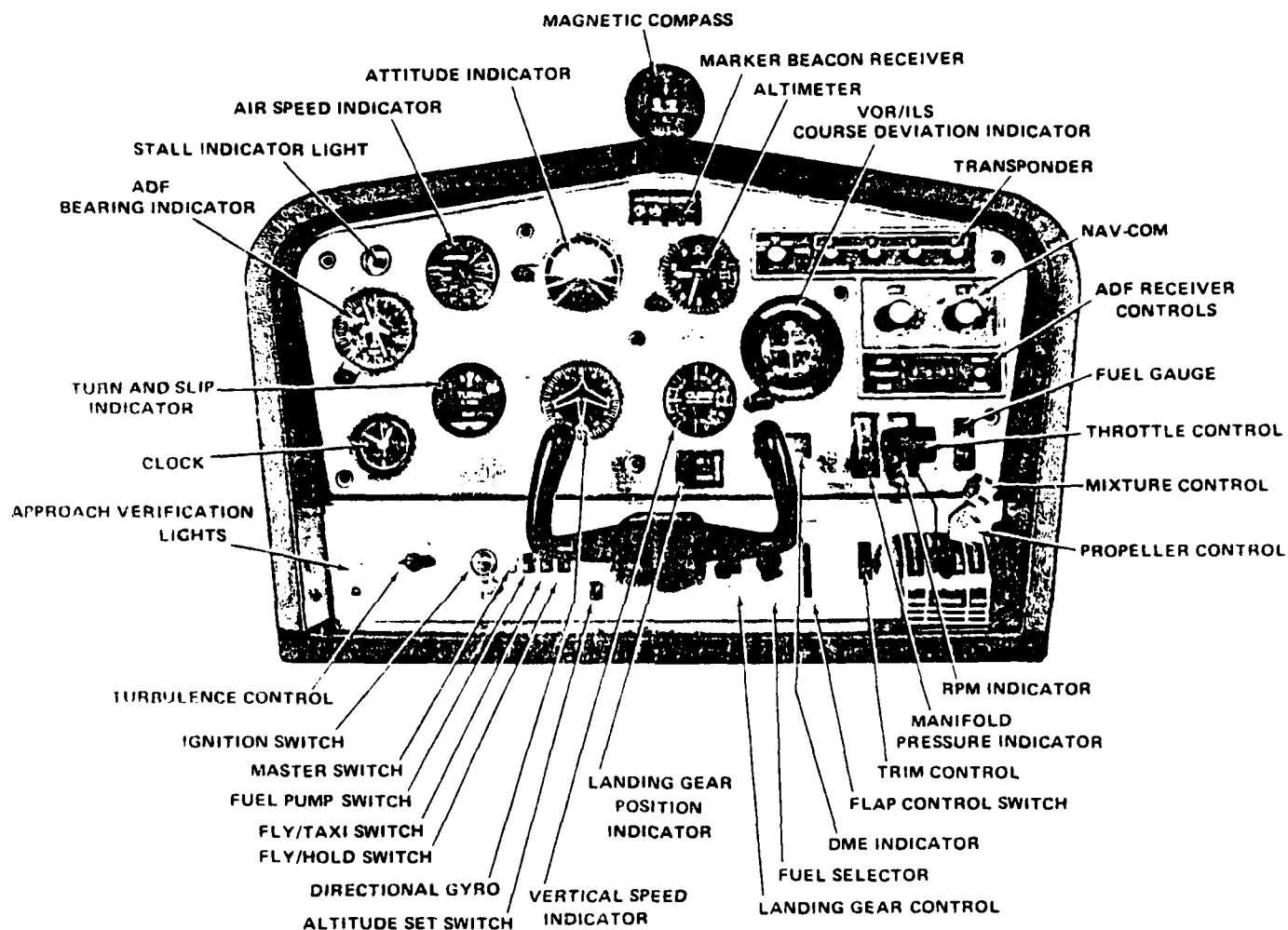
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Figure 6. Flight instruments of the ATC desk-top trainer.

result of unusually poor performance by a few students. In fact, the variability among female cadets was twice that of the other student groups.

Stepwise linear regression was used to determine prediction equations for overall performance on the four flight manuevers. Table 6 summarizes the sample size, multiple R, and significant predictors for various samples. Overall the predictive power of the equations was disappointing. However, several trends did emerge. First, the best predictor in the overall equation was institution suggesting that separate equations for each school were desirable. When separate equations were developed for each institution, no common predictors occurred. The best predictor of VPI undergraduate performance was an information processing test (Map Memory), whereas psychomotor tests predicted the performance of the cadets. In addition, sex was the best predictor for the cadets' performance, indicating that separate equations for male and female cadets are needed. Indeed, no common predictors occurred when separate equations were developed for male cadets versus female cadets.

The limited predictive ability of the equations may be related to various factors including the short duration of training and the simplicity of the flight tasks. Indeed Koonce and McCloy (1980a) report an independent study conducted at the Air Force Academy where performance on a complex flight manuever (chandelle) involving a higher cognitive component was well-predicted by the same pretest battery developed at VPI.

TABLE 6

Sample Size, Multiple R, and Significant Predictors of Total Booklet Score for the Eight ATC Manuevers for Various Samples

Sample	N	R	Significant Predictors (p<.05)		
Combined	200	.44	INST	PTD2V	CC
Males	100	.32	PTD2Z		
Females	100	.49	INST	CC	PR
Air Force Academy	100	.54	SX	PR	PTD2V
Males	50	.52	PTD2Z	IP	
Females	50	.36	PR		
VPI	100	.36	MM		
Males	50	.51	MM	PTD1	
Females	50	.33	MM		

    INST = Institution
    SX = Sex of Student
    CC = Cube Comparison Test
    IP = Identicl Pictures Test
    MM = Map Memory Test
    PR = Pursuit Rotor
    PTD1 = PTD Test 1
    PTD2V = PTD Test 2, two-dimensional tracking
    PTD2Z = PTD Test 2, one-dimensional tracking

In addition, the original set of equations developed at VPI used time-to-train rather than transfer performance as the dependent variable. In all of the studies, transfer performance was much more difficult to predict using only pretask predictors. In another follow-up study at the Air Force Academy using the VPI pretest battery, Koonce and McCloy (1980b) found higher multiple Rs using trials-to-criterion as the dependent variable rather than performance on a single transfer trial. Finally, the findings from the present

research do suggest that a certain amount of caution is warranted in using prediction equations developed on male populations to predict the performance of females. For adequate prediction equations, the training designer must use the appropriate student population in order to insure acceptable predictive power.

Additional Training Environments

In order to establish the difficulty of developing prediction equations for other training tasks and training techniques, a final research study was conducted. The primary objective of the research was to generate equations for the fixed-difficulty, computer-adapted, and learner-adapted training conditions using a slightly modified tracking task. A total of 90 subjects was randomly assigned to one of the three training conditions. Half of the subjects in each condition were female.

The primary differences in the tracking task were in the method used to generate the position of the forcing function symbol and the use of pure acceleration control system dynamics.

Table 7 summarizes the regression equations obtained for each of the three training conditions for time-to-learn the modified tracking task. It is obvious that the equations were not only lower in predictive power than the equations obtained in the previous studies, but also the predictors were different. Therefore, the development of training assignment

TABLE 7

Regression Equations for Training Time-to-Exit for Each of Three Training Conditions with the Modified Tracking Task

---

Fixed-Difficulty Training

$$TE_{FD} = 822.9 + 351.2*SX - 50.7*PR$$

$$n = 30$$
$$R^2 = .25$$
$$p = .02$$

Computer-Adapted Training

$$TE_{CA} = 1616.2 - 38.6*PR$$

$$n = 30$$
$$R^2 = .06$$
$$p = .18$$

Learner-Controlled Training

$$TE_{LC} = 880.13 + 594.0*SX - 59.2*PR$$

$$n = 30$$
$$R^2 = .47$$
$$p = .0002$$

SX = Sex of Student
CC = Cube Comparisons Test
IP = Identical Pictures Test
MM = Map Memory Test
PR = Pursuit Rotor

prediction equations seems to be both population and task specific.

Conclusions on Macroadaption

Several conclusions from this programmatic research effort on macroadaption are warranted.

(1)   The study to evaluate the effectiveness of regression models for training group assignment clearly demonstrated the advantages of the approach both in reducing average training time and intersubject variability.

(2)   The success of the approach is intimately linked with the predictive power of the equations. This limitation became clear with subsequent studies where it was determined that the prediction models were dependent on subject population, the dependent variable predicted, the task, and the training type.

(3) Development and validation of an endless stream of separate prediction equations would be prohibitive in a real-world training setting. The only exception would be a frequently offered training course involving large numbers of students in which the intersubject performance variability using a single training approach was substantial. In this case it might be cost-effective to offer several training alternatives and to develop the necessary prediction equations to assign students to the best training condition.

(4)   In no circumstances should the time required for subject pretesting exceed the savings in training time achieved using this assignment technique.

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PUBLICATIONS

During the contract, 11 papers were published or submitted for publication, and 12 papers were presented at national and international meetings. These publications include discussions of the various macromodel and micromodel approaches explored during the contract to optimize individual motor skills training. Three annual technical reports have been issued. In addition, three masters theses were completed as part of the contract research. Citations for these papers are given below. With the exception of those papers noted with an asterisk, all papers have been included in the appendices of previous annual reports.

Papers Presented at Meetings

Williges, B. H., Williges, R. C., and Savage, R. E. Models for automated motor skills training. Paper presented at the 21st annual meeting of the Human Factors Society, San Francisco, California, October, 1977.

Savage, R. E., Williges, R. C., and Williges, B. H. Individual differences in motor skill training. Paper presented at the Sixth Psychology in the DoD Symposium, April, 1978.

Williges, B. H., Williges, R. C., and Savage, R. E. Matching initial performance and the measurement of sex differences. Paper presented at the Sixth Psychology in the DoD Symposium, April, 1978.

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Cote, D. O., Williges, B. H., and Williges, R. C. Augmented feedback in adaptive motor skill training. Paper presented the the 22nd annual meeting of the Human Factors Society, Detroit, Michigan, October, 1978.

Savage, R. E., Williges, R. C., and Williges, B. H. Cross-validation of regression equations to predict performance in a pursuit tracking task. Paper presented at the 22nd annual meeting of the Human Factors Society, Detroit, Michigan, October, 1978.

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Williges, R. C. and Williges, B. H. Automated motor skills training optimized for individual differences. Paper presented at the Review of Air Force Sponsored Basic Research, Flight and Technical Training, United States Air Force Academy, March, 1979.

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Savage, R. E. A multiple regression information processing approach for assigning individuals to a training strategy. Masters thesis. Virginia Polytechnic Institute and State University, February, 1979.

Cote, D. O. The combined effects of various types of augmented feedback and two training procedures on motor skill learning. Masters thesis. Virginia Polytechnic Institute and State University, March, 1979.

**Becker, R. J. The optimization of computerized motor skills training: Prediction of performance in fixed, adaptive, and learner-controlled training conditions. Masters thesis. Virginia Polytechnic Institute and State University, August, 1980.

** See Appendix B.

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APPENDIX A

Augmented Feedback in Adaptive Motor Skill Training

Augmented Feedback in Adaptive Motor Skill Training

DAVID O. COTE, U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, and BEVERLY H. WILLIGES and ROBERT C. WILLIGES[1], Virginia Polytechnic Institute and State University

Two studies are presented in which a two-dimensional pursuit tracking task was used to teach a complex perceptual motor skill. The primary emphasis in these studies was to test the need for augmented task difficulty feedback in adaptive training situations where changes in task difficulty rather than performance improvements represent training progress. Augmented feedback was provided either auditorially, visually, or both. However, no reliable effects due to feedback were found in either training time-to-criterion or transfer tracking accuracy. In both studies students trained adaptively performed more accurately in transfer.

INTRODUCTION

Most training situations encountered are of the open-loop variety. System variation occurs only in terms of improvement in the student's overall performance level. In open-loop training situations no feedback is provided to the system based upon the learner's response. Closed-loop training systems, such as adaptive training models, differ in that student response is compared to a desired response and some aspect of the system (e.g., task difficulty) is modified in order to maintain a relatively constant performance level throughout training. System variation is accounted for solely by changes in the task over time.

Kelley (1969), one of the originators of adaptive training models for motor skills training, cautioned that students in an adaptive training system are deprived of knowledge of results in terms of noticeable performance improvement. To overcome this deficiency he suggested that a meter giving the exact level of task difficulty at each moment be provided in adaptive training systems. However, although several applied training systems using adaptive techniques have employed such meters (e.g., Caro, 1969), no empirical test of the usefulness of this type of augmented feedback has been made.

This paper briefly reports the results of two experiments designed to evaluate the need for augmented task difficulty feedback in adaptive training. In each study students learned a two-dimensional pursuit tracking task using either fixed

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difficulty or adaptive training techniques. In Study I, feedback of task difficulty and tracking error was presented visually. In Study II, the feedback was presented visually, auditorily, or both to test whether visual information overload had influenced the use of feedback in Study I.

METHOD

Tracking Task

Both experiments were divided into two sessions, a training session and a transfer session. The same two-dimensional pursuit tracking task was used in both training and transfer (see Figure 1). Random band-limited functions controlled the movement of the pursuit symbol (X); the forcing function of the tracking symbol (O) was generated from the output of an isometric control stick.

-----------Insert Figure 1 about here.------------

The effective tracking area on the Textronix 4014-1 display was 12.7 cm X 12.7 cm with the visual feedback bars appearing outside of this area. Viewing distance was kept constant at one meter by using a headrest. If the subject fixated on the center of the display, the feedback bars were in peripheral vision.

The feedback bars presented tracking accuracy and task difficulty information. As performance improved, the feedback bars would move upward. Whenever tracking accuracy or task difficulty reached criterion, that feedback bar would no longer appear on the screen.

When auditory feedback was provided, two tones were presented. Tracking accuracy was indicated by a continuous, 2000 Hz tone varying in amplitude from 46 dB to 51 dB as the controlled symbol moved further from the pursuit symbol. Task difficulty was indicated by 400 Hz, 46 dB "beeps." As task difficulty increased, the frequency of the beeps increased from one every 400 ms to 20 per s. Whenever the criterion level of task difficulty or accuracy was achieved, the tones were not presented. The frequencies and amplitudes of the two tones were selected such that no masking occurred.

In the adaptive training condition task difficulty was defined in terms of the movement speed of the pursuit symbol. The training session proceeded in 3 min-sessions with 1 min breaks until the subjects reached the exit criterion defined in terms of both tracking accuracy and task difficulty. After a few minutes rest students were presented a 6 min transfer task identical to the training task except that no feedback was presented and three levels of tracking difficulty were presented for 2 min each. They were the training exit criterion level of task difficulty, 0.5 times the exit criterion level of difficulty, and 1.5 times the exit criterion level of difficulty.

Experimental Conditions

In Study I, two levels of training type (fixed-difficulty or adaptive) were crossed with two levels of feedback (visual feedback bars present or no feedback). In Study II, the same two

training types were crossed with four levels of feedback (auditory feedback, visual feedback, auditory and visual feedback, or no feedback).

Subjects

To avoid tracking differences due to the sex of the subject only males were used in each study. All were right-handed and naive to the tracking task. Each had passed a minimum visual acuity test of 20/25 vision, both near and far. In Study I, 24 students were divided equally among the four training situations; in Study II, 96 subjects were divided equally among the eight training conditions.

RESULTS

Although the results of Study I and Study II were essentially identical, they are presented separately below.

Study I

Training. A two-factor analysis of variance of time-to-exit scores yielded no significant differences in training time due either to training procedure or the presence or absence of visual augmented feedback ($p > 0.10$). Table 1 summarizes the mean time-to-exit scores for each group.

----------Insert Table 1 about here.----------

Transfer.   An analysis of variance on vector root mean square (rms) tracking error integrated over each minute of the transfer task was conducted with training procedure, feedback in training, and level of difficulty during transfer as factors. The main effect of level of difficulty was significant, $F(2,40)=285.4$, $p<0.0001$,   indicating that the three levels presented in transfer did represent different skill levels. Tracking error increased with greater task difficulty (10.5%, 15.9%, and 22.5%, respectively).

A more important result from the analysis of variance was the finding that training procedure had a significant effect upon transfer performance, $F(1,20)=9.24$, $p=0.0065$.   The mean vector error for those trained adaptively was 12.4%,   whereas the mean vector error for students in the fixed-difficulty conditions was 14.1%.   The main effect of feedback was not significant ($p>0.45$), nor were any interactions ($p>0.10$).

Study II

Training.   Table 1 presents the mean time-to-exit scores for the eight training/feedback groups.   A two-way analysis of variance on time-to-criterion scores yielded no reliable effects due to training procedure or augmented feedback on training time ($p>0.25$).

Transfer.   An analysis of variance on vector rms tracking error integrated over each minute of the transfer task was conducted with training procedure, feedback in training, and

level of task difficulty during transfer as factors. The main effect of level of task difficulty was significant ($p<0.0001$), indicating that the three levels of task difficulty presented in transfer did represent different skill levels. Tracking error increased with greater task difficulty (6.4%, 9.4%, and 12.3%, respectively).

Again the more important result was the finding that training procedure had a significant effect upon transfer performance ($p=0.025$). The mean vector error of those trained adaptively was 9.0%, whereas the mean vector error of those trained in the fixed-difficulty condition was 9.7%. As in Study I neither the main effect of feedback in training nor any of the interactions was reliable suggesting that the results of Study I cannot be attributed to visual information overload.

DISCUSSION

Augmented Feedback

No significant effect due to augmented feedback was found in training or transfer in either study. One could hypothesize that the failure to find a feedback effect was the result of an overall operator information overload. However, this hypothesis is not consistent with questionnaire data collected in Study II where a majority of the students indicated that rather than ignore the feedback, they had used the augmented feedback to learn the task. This would not be logical in an information

overload situation. Another explanation relevant to this finding
is given by Michelli (1966).   When he varied the amount of
augmented feedback presented and the discernibility of the
intrinsic feedback, he found augmented feedback to be only
marginally beneficial in tasks with clearly discernible intrinsic
feedback.   With the pursuit tracking task used in these studies,
the augmented feedback provided no new information in the fixed-
difficulty situation and very little information in the adaptive
training situation that was not already available from the task
itself.

Adaptive training   proved superior   to fixed-difficulty
training in terms of transfer task performance regardless of the
presence or absence of augmented task difficulty feedback. These
findings suggest that the use of a task difficulty meter in
adaptive training situations as proposed by Kelley (1969)   is
unwarranted.   Obviously, one important limitation of the present
studies is the relatively brief training period which may have
had an impact on the need for augmented feedback.

Training Procedure

In both studies small,   but statistically reliable,
differences in performance in transfer favored adaptive training.
One explanation for this finding is that the adaptive group had a
larger amount of practice at various levels of task difficulty.
This is, of course, a basic feature of an adaptive training
system, and in situations where the operational task will involve

various task difficulty conditions, an adaptive training environment may be beneficial.

ACKNOWLEDGMENTS

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TABLE 1

Mean Time-to Criterion (min) for Each Experimental Group

Feedback	Adaptive	Fixed-Difficulty
Study I		
Visual	24.1	17.7
None	17.7	23.7
Study II		
Visual	14.2	13.4
Auditory	14.6	14.3
A-V	15.3	12.0
None	17.7	17.0

LIST OF FIGURES

BIOGRAPHY

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BIOGRAPHY

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BIOGRAPHY

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APPENDIX B

The Optimization of Computerized Motor Skills Training:

Prediction of Performance in Fixed, Adaptive, and

Learner-Controlled Training Conditions

THE OPTIMIZATION OF COMPUTERIZED MOTOR SKILLS TRAINING:

PREDICTION OF PERFORMANCE IN FIXED, ADAPTIVE, AND

LEARNER-CONTROLLED TRAINING CONDITIONS

by

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INTRODUCTION

Background of the Problem

Research in the area of training has become progressively more concerned with the role of individual differences in the training program. The literature points to a need for: (1) identification and measurement of aspects of the individual differences pertinent to the specific skill being taught, (2) accommodation of these differences in the training program, (3) capitalizing on individual differences in order to optimize a specific training strategy or program, and (4) pragmatic use of the information concerning individual differences in the design and implementation of training programs. Glaser (1970) states that the goal of training research should be the determination of interactions between individual measurements and training strategies.

Several approaches to the individualization of instruction may be found in the literature. The adaptive training model optimizes training by individually adjusting task difficulty for a wide range of skill levels (Williges and Williges, 1977). In this model, the learner's errors are maintained at a constant level as the difficulty of the task is varied. With improvement, task difficulty increases, i.e., training automatically becomes harder as skill progresses. Adaptive variables are manipulated so as to affect the difficulty of the task systematically. These adaptive variables may take the form of display changes, task demands, augmented feedback, or

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environmental changes. Adaptive training techniques have been used successfully to teach motor skills (Hudson, 1962; Kelley, 1962; 1966; 1967; Gaines, 1967; 1968; and Caro, 1969).

A second training model, which is referred to as a learner-controlled training strategy, allows the student to control the training strategy in either of two ways: (1) decisions about strategy, and (2) decisions about content (Merrill, 1973). The original research in the area of learner-controlled training was conducted by Mager (1961), who found that subjects who were given complete control of lesson strategy had a subjectively better learning experience and required less time-to-train as compared to teacher-controlled strategies.

More recently, research concerning learner-controlled training (McCann, Hurlock, and Lahey, 1973, and Lahey, Hurlock, and McCann, 1973) has shown that: (1) learner-controlled instruction has a motivational effect upon students, (2) no interference with instruction occurs due to learner-controlled strategies, and (3) this strategy can, in some cases, result in reduced training time.

A study by Williges and Williges (1977) compared the adaptive and learner-controlled training strategies in the training of subjects on a two-dimensional pursuit-tracking task with a fixed-difficulty control condition. Students trained under learner-controlled procedures had less tracking error during transfer than did those trained under fixed-difficulty or automatic-adaptive strategies. These results indicate that

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students are capable of effective manipulation of the learning situation (Williges and Williges, 1977).

Other theories concerning the role of individual differences in training have been posited. For example, information processing models have been proposed as an approach to individualized motor skills training. Individual differences in the central human mechanisms operating between sensory input and motor output have been explored by proponents of these models. In general, the emphasis is on perception, decision-making, and retrieval capabilities, i.e., the components of these central mechanisms. The premise is that limitations in these mechanisms can limit performance.

Marteniuk (1976), an information processing theorist, states that performance of a motor skill entails manipulation of information in some way. Information processing refers to this use of information leading to movement. Welford (1968) asserted that an understanding of how a person processes situational or response-induced information suggests instructional techniques that would be favorable to the learner.

Development of the Multiple Regression Approach to Individualized Instruction

The objective of research dealing with individual differences in motor skills training is twofold. First, one hopes to attain the ability to use information about individual differences in the development of decision rules for the

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assignment of students to a particular training strategy. Second, it is expected that this decision rule should result in a savings of training time and/or a maximization of transfer of training.

This thesis research used multiple regression as a method for the enhancement of individualized motor skills training strategies. Previous research supports this approach (Savage, Williges, and Williges, 1978; 1979). At the onset of the thesis research, it was hypothesized that a multiple-regression approach would aid in optimizing motor skills training strategies by identifying those individuals who can best operate under the specific characteristics of each strategy type to be investigated.

A technique for the selection of a training strategy based on individual measures was developed by Savage, Williges, and Williges (1978; 1979) for the training of subjects on a two-dimensional pursuit tracking task. The development of the technique included the use of a multiple-regression approach.

The Savage et al. endeavor began by generating multiple regression equations predicting time-to-train in two different training strategies, i.e., a fixed-difficulty and an adaptive training strategy. Scores on an information processing and motor pretest battery served as the independent or predictor variables. Three reliable regression equations were generated which predicted time to attain exit criterion performance for each condition. The three equations consisted of an overall predictive equation and two equations based on the sex of the

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subject.   It was hypothesized that more variance could be accounted for by developing separate regression equations for each sex,   due to results reported by Williges and Williges (1978).   This hypothesis was subsequently confirmed,   with equations based on sex accounting for a larger proportion of variance than the overall equations in all but the fixed-difficulty training condition using females.

This first study proved to be the beginning of a research program which sought to integrate empirically the motor learning literature into a viable approach for capitalizing on individual differences in the training of motor skills. Subsequently, Savage et al. (1978) proceeded with a double cross-validation of the regression equations with a second sample of subjects.

. Finally, Savage et al. (1979) tested the utility of the regression approach by using it as a decision rule for the assignment of subjects to a training strategy (condition). Subjects were matched, mismatched, or randomly assigned to training conditions according to their respective predicted time-to-exit scores. It was demonstrated that a 47% savings of training time resulted when subjects were matched to a training condition as compared to those that were randomly assigned.   A 53% savings resulted when subjects were matched as opposed to mismatched with a training strategy. These results support the use of a regression approach as a decision rule for assignment of subjects to a particular training strategy.   The advantage of this methodology over such techniques as discriminant

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analysis or "Aptitude-Treatment-Interaction" (Cronbach, 1975:
Cronbach and Snow, 1977) lies in the fact that actual
performance data are used in the development of a decision
rule, and students are neither rigidly nor categorically
classified.

In summary, the work of Savage et al. (1978; 1979) has
demonstrated: (1) the use of information processing variables
as predictors is significant in predicting pursuit-tracking
performance, (2) the use of a regression approach is a valid
technique for prediction of pursuit tracking performance and
determination of significant predictor variables, and (3) an
approach for determining decision rules for assignment of
subjects to a particular training strategy was successfully
implemented.

Prediction of Flight Training Performance: Joint Effort
Following the development of the multiple-regression
approach to individualized motor skills training (Savage et
al., 1978; 1979), an experiment was conducted which sought to
extend the application of this approach to the real-world task
of simulated flight training. The study was conducted as a
joint research effort between Virginia Polytechnic Institute
and State University and the United States Air Force Academy,
with the author of this thesis serving as research assistant.
The experiment and its results are reported here to lend an
historical perspective to the development of the multiple-
regression methodology leading to this thesis. However, future

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reference will be made to these results in the discussion of the thesis research.

Fifty male and fifty female subjects from each institution (200 subjects total) were used to generate regression equations predicting flight training performance. With the exception of two new motor tests, the pretest battery (the scores of which comprised the independent or predictor variables) was identical to that used by Savage et al. Subjects were trained and tested on four flight maneuvers, in both normal and turbulent conditions, using an ATC 610 J/K table top flight simulator. Scores on the maneuvers were combined to create an overall performance score which served as the dependent variable.

Table 1 shows a summary of the resultant regression equations predicting flight training performance. The table includes the population sample of interest, the associated coefficient of multiple determination, and the significant predictor variables in order of the largest weighting to the smallest. It can be observed that overall predictive ability was disappointingly low. Although several factors may have contributed to the limited predictive ability of these equations, the observation to be made relative to this thesis is the consistent inability to account for a significant proportion of variance. It can be argued that the methodology was inappropriately applied or that the dependent variable was of too complex a nature. Exploration of the multiple-regression approach was continued, however, and has culminated in this thesis effort.

Table 1. Joint Effort Results

	FLIGHT TRAINING PERFORMANCE SCORES	
SAMPLE	R^2	SIGNIFICANT PREDICTORS
Combined	.19	INST, PTD2, CC
Males	.10	PTD2
Females	.24	INST, CC, PR
A. F. Academy	.29	SX, PR, PTD2
Males	.27	PTD2, IP
Females	.13	PR
VPI & SU	.13	MM
Males	.26	MM, PTD1
Females	.11	MM

INST = Institution; VPI & SU or A. F. Academy
SX   = Sex; Male or Female
IP   = Identical Pictures Test
MM   = Map Memory Test
CC   = Cube Comparisons Test
MT   = Maze Tracing Speed Test
EFT = Embedded Figures Test
PR   = Pursuit rotor
PTD1 = Psychomotor Test Device Test 1
PTD2 = Psychomotor Test Device Test 2

Thesis Research Objective

The Savage et al. research (1978; 1979) was the first to
describe a multiple-regression approach to the
individualization of instruction in motor skills learning. The
utility of the approach was demonstrated for fixed-difficulty
and computer-adapted training strategies. However, a third
training strategy, a learner-controlled strategy, has been
shown to be an advantageous approach to the individualization
of motor skills learning (Williges and Williges, 1977).
Therefore, the primary objective of this thesis research will

be the generation of regression equations predicting training time in three training conditions: (1) fixed difficulty, (2) computer-adapted, and (3) learner-controlled. Subsequently, a comparison of the three strategies will be made with regard to training time.

A second objective of the thesis research will be the consideration of transfer of training performance as the criterion of interest. Regression equations predicting transfer task performance (mean rms vector tracking error) will be generated for each of the three training strategies with regard to transfer of training performance. Previously, Williges, Williges, and Savage (1973) generated regression equations for the transfer task employing the two-dimensional pursuit-tracking apparatus used to develop the multiple regression methodology. The objective of this approach was the development of a decision rule based on transfer of training performance, which is often considered by the trainer to be more important than a savings of training time. With the exception of equations for females, no reliable equations predicting transfer task performance were generated.

Thirdly, Savage et al. (1979) outlined the necessity of replication of their research in order to establish the validity of the multiple regression approach. The thesis research will encompass the attempt to replicate, as closely as possible, the generation of regression equations predicting training time for the fixed-difficulty and computer-adapted training conditions. Of primary concern here will be the

replication of the reliable predictive ability demonstrated by Savage et al.

Preliminary Study

A preliminary study was conducted in order to obtain an indication of the behavior of the independent (predictor) variables in the regression equations for the new learner-controlled training condition. Prediction of training time for this condition using the pretest battery described by Savage, Williges, and Williges (1978) had never been attempted previously. Of primary importance was the determination of the significant predictors for the learner-controlled training condition. Once accomplished, this would aid in the refinement of the pretest battery to be used in the thesis research.

Nine male and nine female subjects were used to generate regression equations predicting training time for the learner-controlled training condition. All subjects were paid volunteers.

Each subject participated in three experimental sessions. During the first session, subjects were administered the paper-and-pencil test portion of the pretest battery outlined by Savage et al. (1978). This consisted of a statement of subjects' rights, the Identical Pictures Test, the Map Memory Test, the Cube Comparisons Test, and the Maze Tracing Speed Test. The second session consisted of the Embedded Figures Test, six 30-second trials on a pursuit rotor, and testing on the Psychomotor Test Device Tests 1 and 2. Since one of the

objectives of the preliminary study was the modification of the pretest battery, its components will not be discussed in detail at this time. Rather, a full discussion of the pretest battery to be used as predictors for the thesis research will be given in the METHOD section.

In the third session, subjects were trained on the two-dimensional pursuit-tracking task, with all subjects receiving the learner-controlled training condition. After a short rest period, a seven-minute transfer task was performed. The transfer task was identical to the training task, except that no visual feedback was presented. In addition, task difficulty was automatically varied among three levels. Thus, subjects had no control over task difficulty during the transfer task. Again, full descriptions of these tasks relative to each training condition will be given in discussion of the thesis research.

Five stepwise regression procedures were used to generate regression equations predicting training time for the learner-controlled training condition. The final step of the Statistical Analysis System's STEPWISE procedure served as the criterion for choice of the predictive equation.

Table 2 shows the regression equation obtained in the preliminary study. It can be seen that the proportion of variance accounted for by the equation was quite high. Thus, an equation predicting training time for the learner-controlled training condition was generated which was consistent with the results obtained by Savage et al. (1978) for the fixed-difficulty and computer-adapted training conditions.

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Table 2. Preliminary study regression equation predicting training time for the new learner-controlled training condition.

$TT = 196.762 + 836.039 \ (SX) - 30.455 \ (CC)$

$R^2 = .80$

$\underline{p} = .0003$

TT = Training time; in seconds
SX = Sex; Male or Female
CC = Cube Comparisons Test

In summary, the preliminary study served to identify the significant predictors for the new learner-controlled training condition. The proportion of variance accounted for was consistent with previous reports for fixed-difficulty and computer-adapted conditions. Previous research had already outlined the significant predictors for the fixed-difficulty and computer-adapted training conditions (Savage et al., 1978). Therefore, the ultimate composition of the pretest battery to be used in the thesis research was determined by the integration of previous empirical results and the preliminary study.

METHOD

Pretest Battery

Scores on an information processing and motor pretest battery served as the independent (predictor) variables for the regression equations generated in the thesis research. Since the thesis research examined three training strategies (fixed-difficulty, computer-adapted, and learner-controlled), the revised pretest battery consisted of a combination of the significant predictors reported by Savage et al. (1978) and those resulting from the preliminary study. Table 3 summarizes the pretest battery components and the associated test-retest reliability coefficient of each (Ekstrom, French, Harman, and Dermen, 1976). Each component of this refined pretest battery will be discussed in the order of its presentation to subjects.

The Identical Pictures Test measures perceptual speed, i.e., an individual's ability to take in and reduce perceptual information. The speed with which one is able to process visually perceived information involves such factors as selective attention, scanning and searching, and pattern recognition. Fleishman (1954) found perceptual speed to be an important factor in motor skill learning. The necessity of rapid detection and filtering of irrelevant information in motor learning is also discussed by Marteniuk (1976).

The Map Memory Test assesses the short-term visual memory capacity of the individual by measuring his/her ability to remember the configuration, location, and orientation of

Table 3. Summary of Pretest Battery Used as Predictor Variables

TEST	RELIABILITY COEFFICIENT
Identical Pictures Test	.84
Map Memory Test	.77
Cube Comparisons Test	.77
Embedded Figures Test	.80
Pursuit Rotor	*

*No reliability data available.

figural material. Several motor learning models postulate the coding of motor information in memory as visual in nature. Keele (1973), Marteniuk and Roy (1972), and Posner (1967) have shown that there is a large number of individual differences in memory capacity of this type. Marteniuk states that memory is an integral part of continuous motor tasks, such as tracking. He goes on to relate memory to various mechanisms of motor performance that comprise theoretical models found in the literature. Adams and Dijkstra (1966) and Posner (1967) present evidence supporting the hypothesis that the form of movement-related information in short-term memory is an "image", and thus visual in nature.

The Cube Comparisons Test evaluates the individual's ability to perceive spatial patterns and maintain a clear spatial perspective of objectives in the environment. Spatial orientation has been shown to be a factor in the coding of motor information (Cratty, 1967; Marteniuk, 1976). Spatial-

visual sensitivity was also demonstrated to be important in early learning (Fleishman and Rich, 1964).

The Identical Pictures Test, the Map Memory Test, and the Cube Comparisons Test were taken from the Kit of factor referenced cognitive tests (Ekstrom, French, Harman, and Dermen, 1976).

Next in order of administration was the Embedded Figures Test (Witkin, Oltman, Raskin, and Karp, 1971). The EFT measures field independence and field dependence, a perceptual ability, the assessment of which yields an indication of an individual's ability to break apart an organized visual field and separate a sought-after component from the overall field presented. Field independence has been shown to be positively correlated with tracking (Benfari and Vitale, 1965). Cratty (1967) has also suggested that analytical perceptual styles, such as field independence, are more important in the early stages of learning.

The last component of the pretest battery was the motor component which consisted of six 30-second trials on a pursuit rotor (Lafayette Instrument Co.). The pursuit rotor measures general pursuit tracking ability. The turntable was 25 cm in diameter, with a target of approximately 2 cm in diameter. Subjects began each trial with the metal stylus resting on the small metal target disk. The turntable then began rotating in a clockwise direction at 50 rpm. Performance on the pursuit rotor has been shown to be negatively correlated with fixed-difficulty (-.71), computer-adapted (-.76), and learner-

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controlled (-.58) training conditions of the two-dimensional pursuit-tracking task used by Savage et al. (pilot study, 1973) and that used in the preliminary study conducted prior to the thesis research.

In summary, the components of the pretest battery have been shown to be measurable factors which are related to the training conditions and the task of interest.

Subjects

Fifteen male and fifteen female subjects were randomly assigned to each of the three training conditions (fixed-difficulty, computer-adapted, and learner-controlled) for a total of 90 subjects. All subjects were paid volunteers. Subjects were required to be right handed, naive to the experiment, and have at least 20/25 near and far vision. Corrected or uncorrected vision was accepted. A Baush and Lomb Orthorater was used to determine visual acuity.

Tracking Task

A two-dimensional pursuit tracking task was used to train subjects under three training strategies. The time-to-train to criterion on this task served as the dependent variable for the regression equations predicting training time. The same task was used in the performance of the transfer task.

Training task. Subjects were trained on the two-dimensional pursuit tracking task illustrated in Figure 1. Four independent, random, band-limited functions were used to

determine the forcing function of the pursuit symbol ("X") on the display. The band-limited functions determined the length of an excursion in each axis and the duration of the vector excursion. The forcing function of the tracking symbol ("O") was generated from the output of an isometric (force) control stick.

The effective tracking area on the display was 12.7 cm X 12.7 cm. Visual feedback was provided (see Figure 1), and appeared outside of this area (8.89 cm from display center). On the left hand side of the display there appeared a bar graph labeled "ACCURACY". The horizontal line at the top of the bar graph indicated performance which was within tolerance, i.e., the "O" was within 10% of the effective screen diagonal of the "X" (1.8 cm). When the "O" was closer than 1.8 cm to the "X", the vertical line disappeared from the display. If a subject moved the "O" outside the tolerance range, the bar reappeared on the display. On the right hand side of the display there appeared a bar graph labeled "DIFFICULTY". As task difficulty increased, the bar approached the horizontal line at the top of the bar graph, which indicated criterion task difficulty. When criterion task difficulty was achieved, the right hand bar graph disappeared from the display. In the fixed-difficulty training condition, the "DIFFICULTY" bar was never presented, since the task was always at the criterion level of difficulty. In the computer-adapted condition, the bar disappeared and reappeared as the subject performed within the tolerance range or moved out of tolerance. The "DIFFICULTY" bar moved
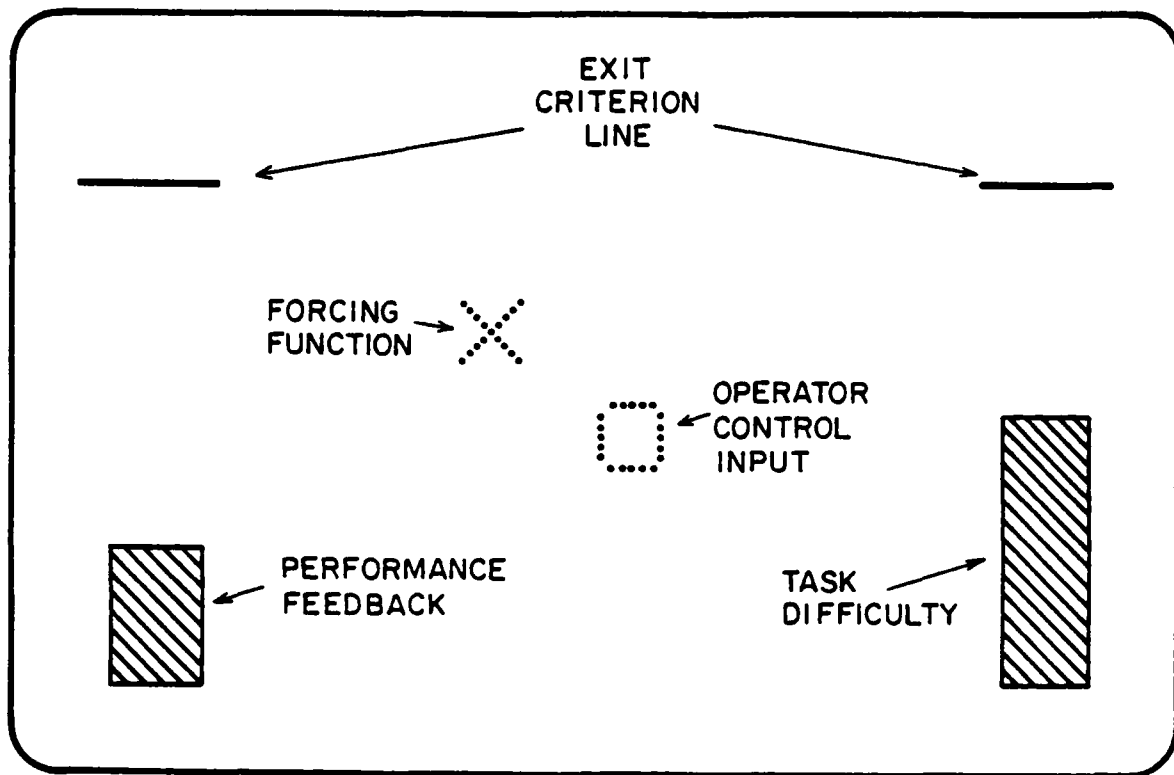
Figure 1. Two-dimensional pursuit tracking task with visual augmented feedback ("ACCURACY" and "DIFFICULTY" were the only labels actually displayed.)

according to inputs from two pushbuttons in the learner-controlled condition. Subjects could increment or decrement task difficulty by depressing one of the two buttons. The feedback presented was necessary in that it provided information not readily apparent in the computer-adapted and learner-controlled training conditions.

Subjects were provided with a forehead rest which kept the display viewing distance at 1 m. The tracking symbology (the "X" and the "O") occupied .64 cm X .48 cm area each. With a subject's point of regard being the display center, the visual angle subtended by the feedback bars was 10.08 deg. Thus, the feedback bars were within the peripheral vision of the subject with fixation on the display center.

Random movement of the pursuit symbol ("X") was generated by simulating a computer-operated control stick. Task difficulty (excursion speed and random movement of the "X" symbol) changed in relation to the deflection of the simulated control stick. The criterion level of task difficulty during training was the maximum possible movement speed of the "X", which was 6.0 cm per second. The control system dynamics were pure acceleration.

In the fixed-difficulty training condition, the speed of the pursuit symbol ("X") was maintained at the criterion level throughout training. Exit criterion performance during training was defined as maintenance of the control output symbol ("O") within 10% of the effective screen diagonal of the pursuit symbol ("X") for a period of 20 continuous seconds.

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For the computer-adapted condition, a small-step adaptive logic was used to vary the speed of the pursuit symbol by changing the maximum deflection of the simulated control stick. A sliding average error was computed and compared to a tolerance limit of 10% of the screen diagonal, or 1.8 cm. A total of 1851 task difficulty steps was used, requiring a minimum time of 111.1 seconds to reach exit criterion level of difficulty.

Subjects were able to increase or decrease task difficulty in the learner-controlled training condition by means of a pushbutton keypad. Strategies for incrementing or decrementing task difficulty were left completely up to the subject. The visual feedback informed the subject when the criterion level of task difficulty was reached. Exit criterion performance was defined in the same manner as for the other trainng conditions.

To avoid fatigue effects, subjects were given a maximum of fifteen, 3-minute trials interspersed with 1-minute rest periods.

Transfer task. After subjects were trained to criterion in one of the three training conditions and given a short rest period, they performed a seven-minute transfer task. The transfer task was identical to the training task with the exception of absence of the visual feedback, and, in the case of those trained under the learner-controlled condition, no control of task difficulty. Transfer task difficulty shifted among three levels, with each level of difficulty presented in the same order for all subjects. These levels were: (1) one

half the exit criterion level of difficulty = 3.0 cm/s, (2)
exit criterion level of difficulty = 6.0 cm/s, and (3) one and
one half times the exit criterion level of difficulty = 9.0
cm/s.

Tracking Task Hardware and Software

The description of the tracking task hardware and software
was adapted from a formal description written by John E. Evans,
III. Mr. Evans is a research associate in the Human Factors
Laboratory at Virginia Polytechnic Institute and State
University.

The training and transfer tracking tasks were generated
using a laboratory developed software package run on a Digital
Equipment Corporation PDP 11/10 digital computer. The tasks
were displayed on a Tektronix 4014-1 computer display. A
Measurement Systems Model 435 two-axis isometric control stick
and a keypad, designed and fabricated by laboratory support
personnel, served as the subject/computer interfaces. The
keypad consisted of two easily depressable buttons which
allowed the subject to increase or decrease task difficulty in
the learner-controlled training condition. Figure 2
illustrates the data acquisition hardware configuration. The
experimenter operates the keyboard at the computer console
screen, thus initializing the data acquisition program and
entering various task parameter values which are stored on the
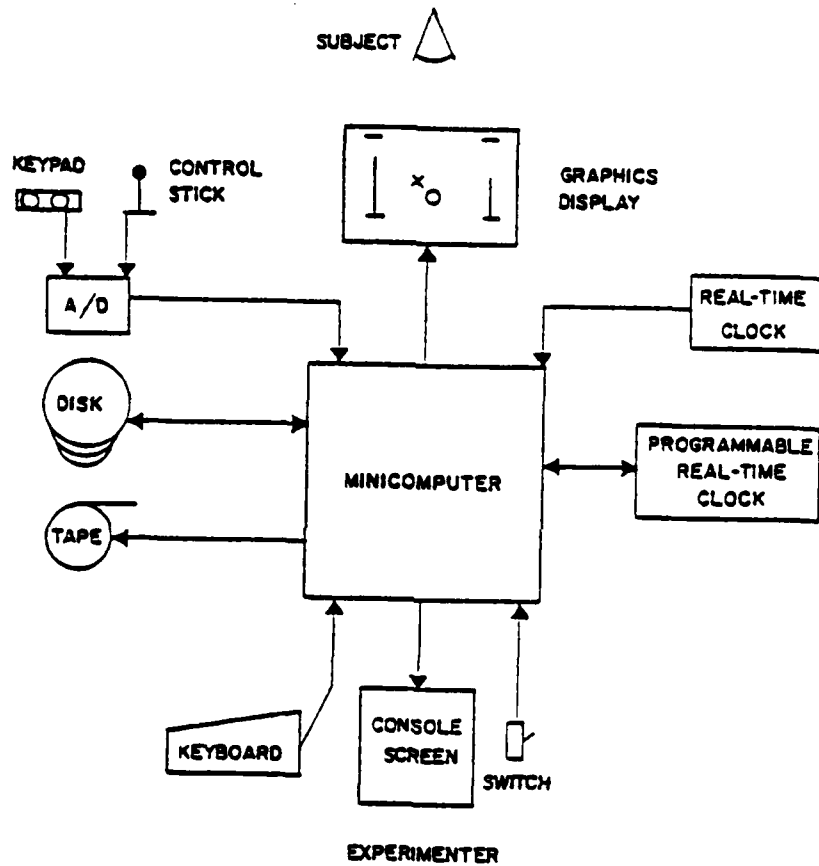disk.

Figure 2.   The equipment setup for the pursuit tracking task.

After initialization of the task parameter values by the experimenter, the motor skills task is presented to the subject on the screen of the Tektronix display. The "O" symbol is controlled by the subject using the isometric control stick, and the pushbutton keypad allows the subject to raise or lower the level of task difficulty in the learner-controlled condition. The A/D (analog to digital) converters digitize the analog control voltages from the joystick and pushbuttons. The programmable clock assures a uniform sampling rate of the joystick and pushbutton outputs and calculates the subsequent graphics update. The timing of the refresh cycle of the dynamic images on the display is controlled by the real-time clock. The static images (the feedback bar levels; see Figure 1) are written in the storage mode of the display. The real-time clock also times the one-minute rest and three-minute trial periods. Should termination of the experiment be warranted, the experimenter is able to halt program execution by setting a switch on the front panel of the minicomputer.

Figure 3 shows a block diagram of the software configuration. The main program supervises and coordinates the various actions of the subroutines. The experimenter provides the subject identification information which is accepted by the subject identification subrountine. The experimenter then enters the parameter values which control characteristics of the tracking task, and which are processed by the parameter entry subroutine. Parameter values may be previously defined and stored on disk by the experimenter, in which case the

SUBJECT IDENT
ENTRY

DEFAULT VAL
UPDATE

PARAMETER
ENTRY

subject cycle = 1 - 8

Tektronix

GRAPHICS
DISPLAY

between trial
messages

7

2

MAIN PROGRAM

60 Hz refresh

DEFAULT VALUE
ENTRY

3

REFRESH
PROCESS

initiate
refresh

SYSTEM
CLOCK

4

5

recording
subject/experiment
info

6

60 ms
display
update

c

INITIALIZE

DISK
OUTPUT

data
recording

a

REAL-TIME
PROCESS

timing,
joystick,

b

keypad

A/D, D/A
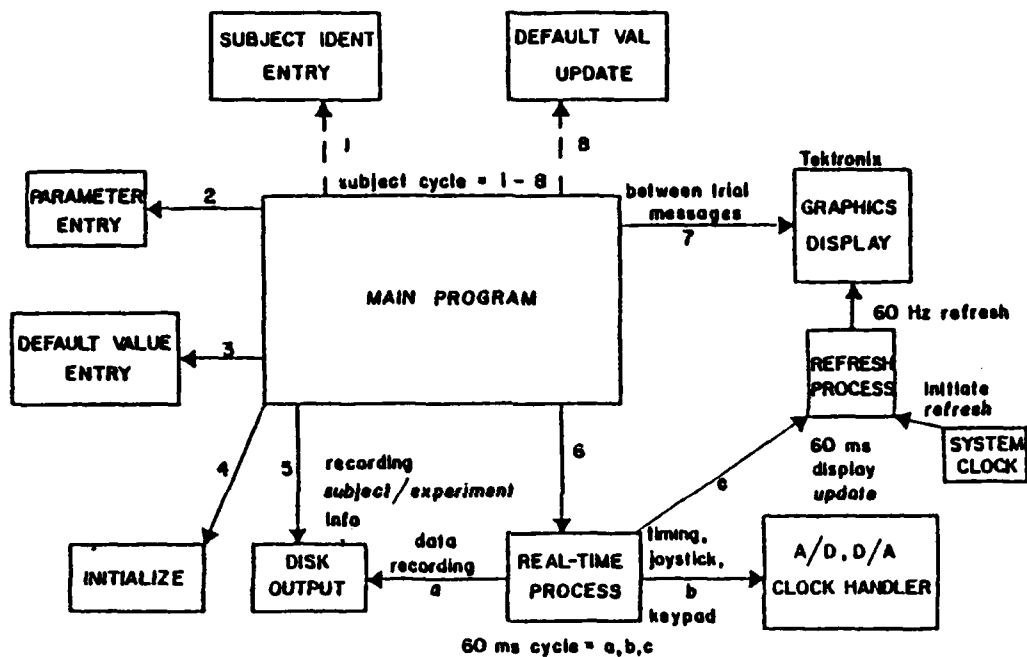
CLOCK HANDLER

60 ms cycle = a,b,c

Figure 3. Block diagram of the data acquisition program.

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default value entry subroutine reads these values. The disk output subroutine then writes this information on disk.

The task parameter values use in the thesis research are presented in Table 4. ALPHA and GAMMA are the percentage of acceleration control for the forcing function symbol ("X") and the controlled symbol ("O") respectively. MAXIPS is the maximum cm/s excursion rate for the forcing function symbol, and MINIPS is the minimum cm/s rate. EXERR is the amount of allowable vector error (tolerance). This parameter defines the 10% tolerance region considered to be "on-target". ACRACY is the percent of vector error required for the upward adaptation of level of difficulty in the computer-adapted training task. The ERATE determined the speed of movement of the "ACCURACY" feedback bar. The inverse of the ERATE value is the time required for the "ACCURACY" feedback bar to travel from 100% to 0% if its movement is constrained to be at the rate of its first decrement. However, since a sliding average error is calculated, this interpretation of ERATE is valid only for very small excursions. The size of the window used in computing the sliding average is derived from ERATE. RATE is the time required for the computer-adapted training condition level of difficulty feedback bar to travel from 0% difficulty to 100% difficulty. The inverse of this parameter is the actual time required. In the fixed-difficulty training condition, the RATE would be zero, which would maintain 100% level of difficulty. RATE also determines the adjustment of task difficulty in response to the pushbutton inputs in the learner-controlled training condition.

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Table 4. Tracking Task Parameter Values

ALPHA	1.00
GAMMA	1.00
MXIPS	12.00 cm/s
MAXIPS	6.00 cm/s
MINIPS	0.01 cm/s
EXERR	0.90
ACRACY	0.10
ERATE	0.0499
RATE	0.008

The initialization subroutine performs all possible precalculations from the parameter values. The graphics display subroutine writes the static portion of the tracking task onto the Tektronix display. The programmable clock controls operation of the real-time process, and uses the A/D and D/A handlers to interface with the display, the joystick, and the pushbuttons. The disk output subroutine records the data from the tracking task. The graphics refresh process (controlled by the real-time clock) synchronizes image updates with image refreshes. The graphics refresh process also initiates the graphics display subprogram which presents the dynamic aspects of the tracking task on the display. The timing of the trials and rest periods is controlled by the main program. The main program also uses the graphics display subroutine to display the "rest", "ready", and "exit" messages to the subject. Finally, parameter values can be updated at the end of the task by the default value update subroutine.

Figures 4, 5, 6, and 7 show flow charts of the real-time data acquisition programs for the fixed-difficulty, computer-adapted, and learner-controlled training tasks, and for the

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transfer task. At the start of the tracking task, the program determines whether the three-minute trial (or the seven-minute transfer task trial) is completed. If the trial is completed, a one-minute rest cycle is initiated (or the task is over if in transfer). If the trial is still in progress, the analog values from the control stick (and pushbuttons in the learner-controlled condition) are inputted and the new position of the control symbol, "O", (and the DIFFICULTY" bar in the learner-controlled condition) is determined. Next, the random values are generated for the forcing function symbol and the new position of the "X" is calcul ted. The updated positions of the symbols are then displayed by the Tektronix display (60 ms cycle for the update calculations and 60 Hz refresh cycle). Rms vector error is then calculated and recorded along with the difficulty of the task.

Several differences in the flow charts should be noted (refer to Figures 4, 5, 6, and 7). If in the transfer task, the task difficulty is updated at each one-minute interval. If in fixed-difficulty training, difficulty is maintained at the criterion level. In the computer-adapted training task, difficulty is adapted upward or downward depending upon subjects' performance within the 10% tolerance range. If in the learner-controlled training condition, the task difficulty is adjusted upward or downward depending on the pushbutton selection of the subject, or is left unchanged if no button is depressed. The feedback bars are updated according to this difficulty and error information.
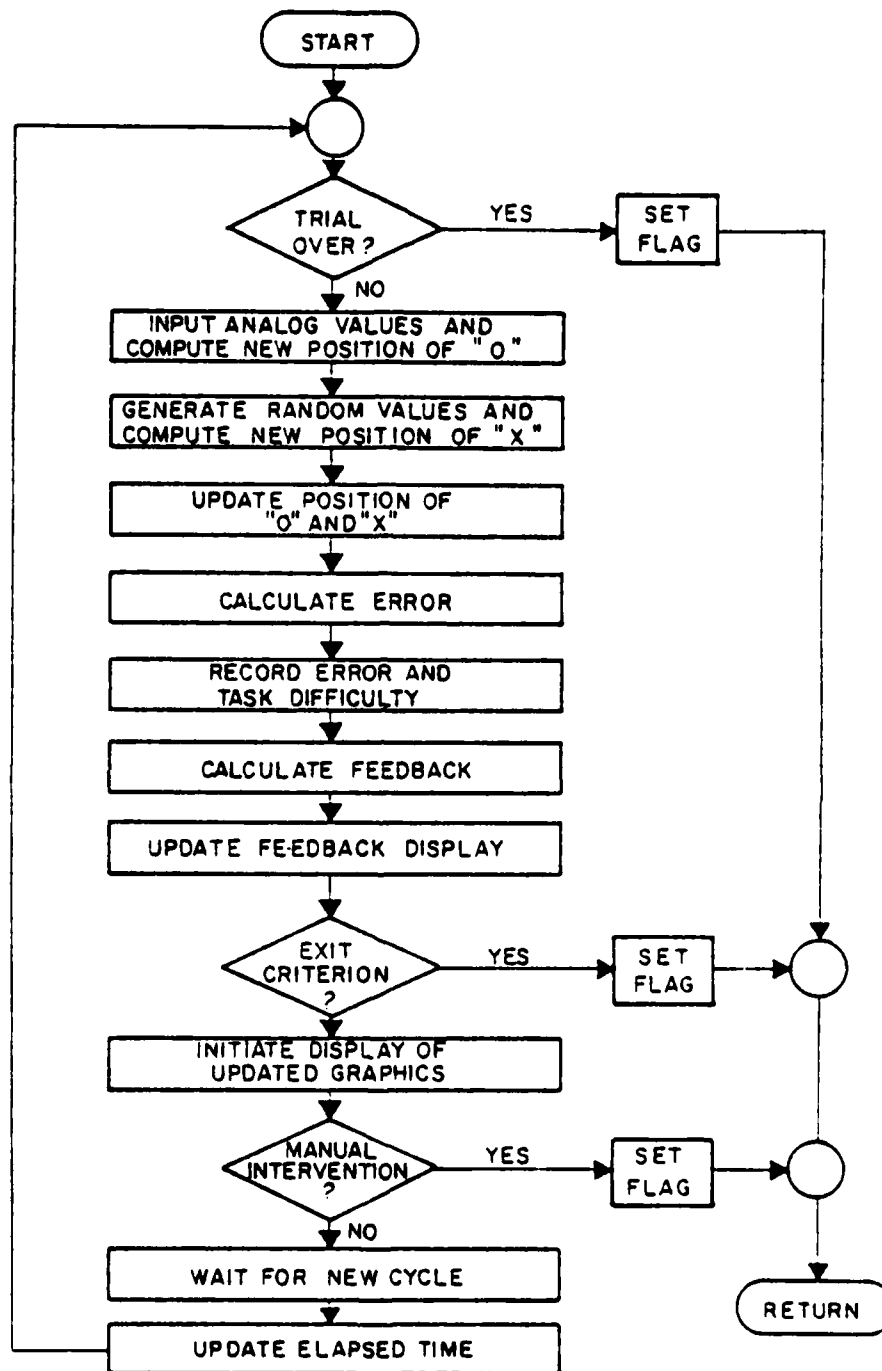
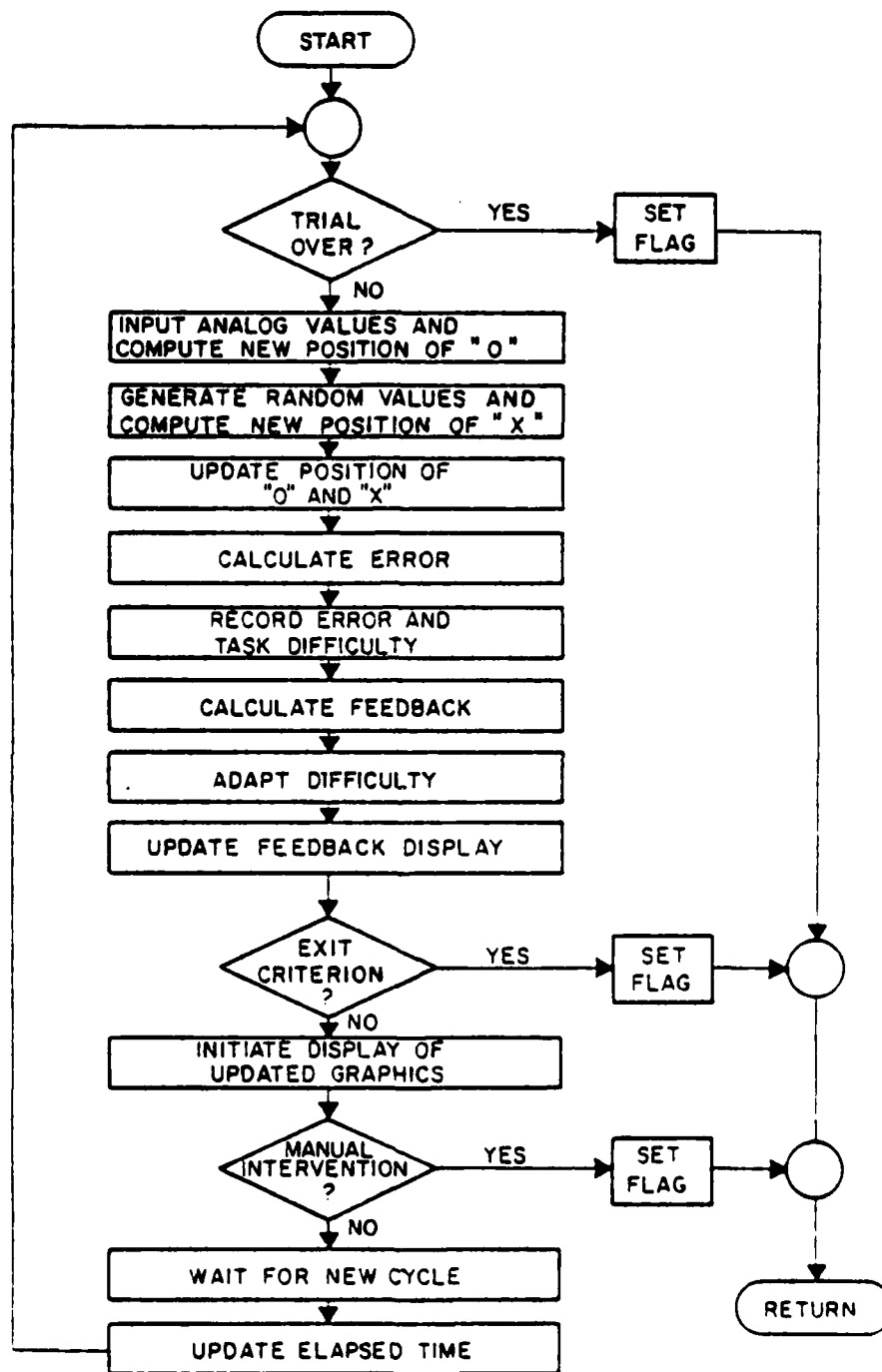Figure 4. Flow diagram of the fixed-difficulty tracking
task.

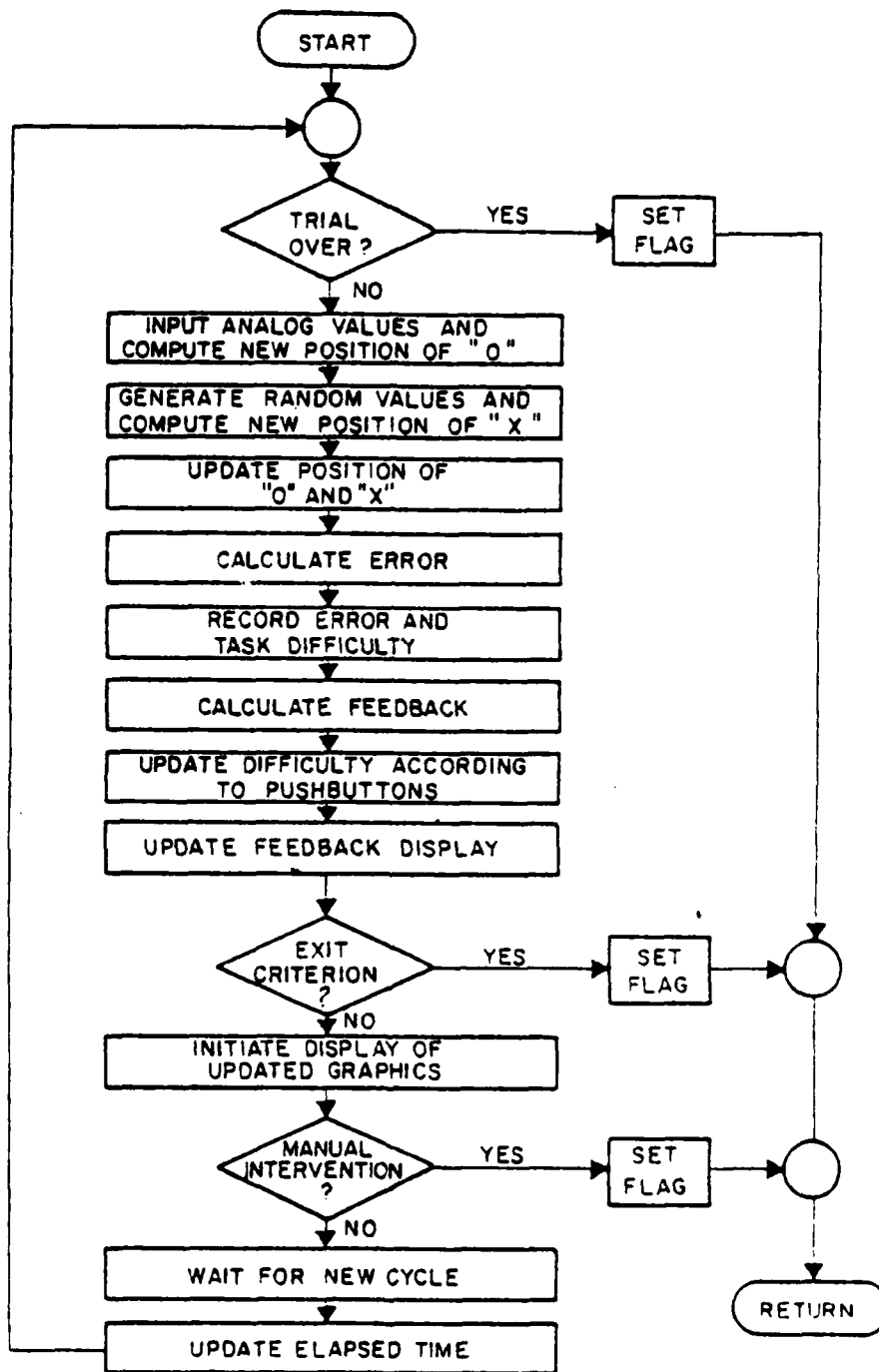Figure 5. Flow diagram of the computer-adapted tracking task.

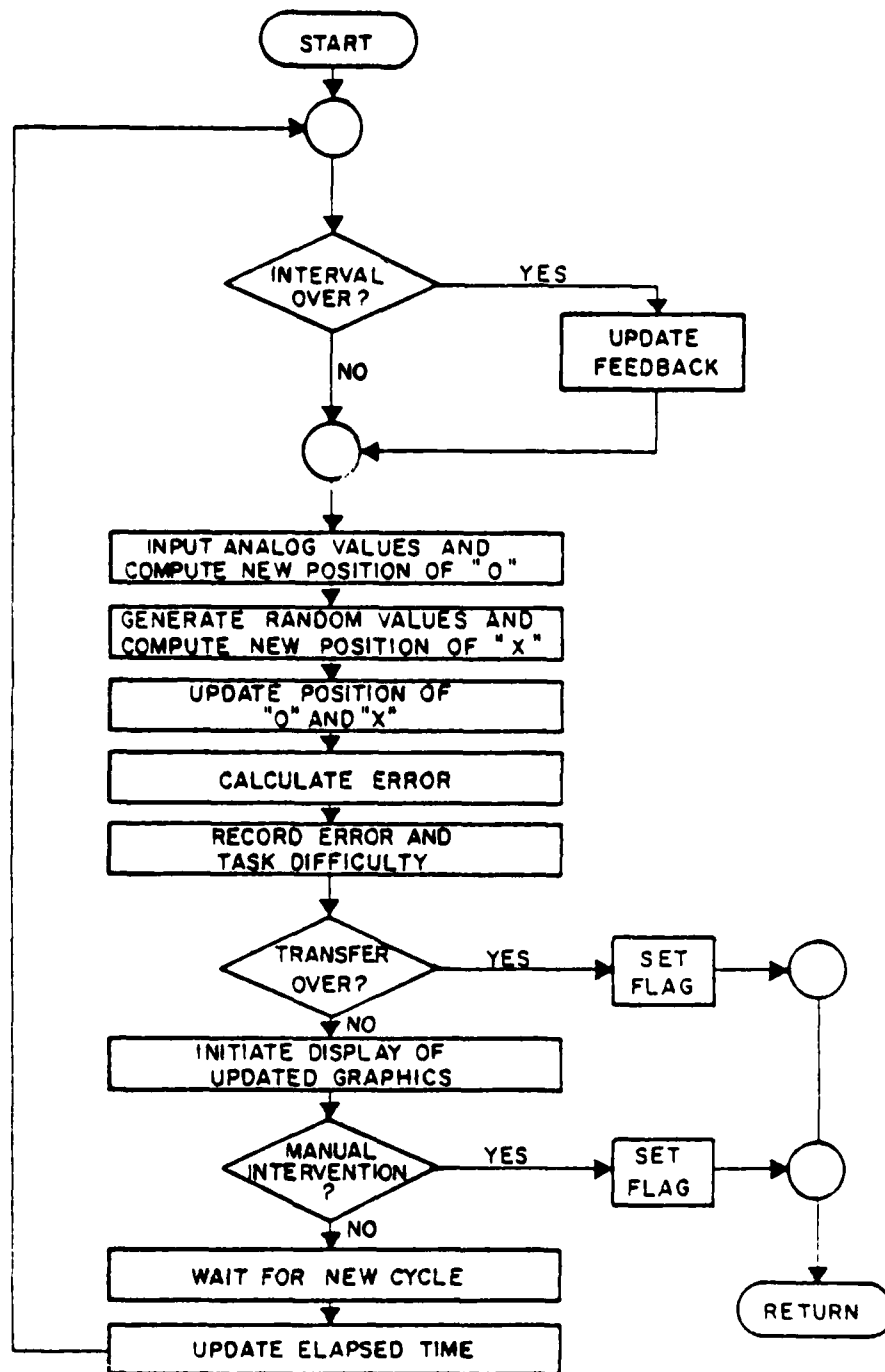Figure 6. Flow diagram of the learner-controlled tracking task.

Figure 7. Flow diagram of the transfer task.

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Finally, the program determines whether the exit criterion requirements have been met. If the requirements have been met, then the task is completed and the time-to-exit (training time) is recorded on disk. If the requirements have not been met, then the updated graphics are displayed. The program lastly checks for manual intervention, i.e., whether or not the front panel switch has been set by the experimenter to terminate the task. If the task has not been terminated in this manner, the program waits for the next 60 ms cycle and updates the elapsed time for the timing of the trial.

Training Conditions

Three training strategies were used to train subjects on the two-dimensional pursuit tracking task, including fixed-difficulty, computer-adapted, and learner-controlled strategies.

The fixed-difficulty training condition uses the traditional approach to motor skills training in which the trainees are presented the task at the criterion level of difficulty at the beginning of training. The task remains at the criterion level of difficulty throughout training, and the student's error decreases as training progresses. This approach obviously does not take individual differences into account.

The computer-adapted training condition uses an adaptive logic to manipulate task difficulty in a closed-loop system (Kelley, 1969). Student performance is measured and compared

to a specified criterion. The closed-loop system then adjusts the difficulty of the training task so as to keep the performance of the student relatively stable throughout training, i.e., the student's error is held constant. The computer-adapted training condition, thus, accommodates and adjusts to individual skills through the feedback loop aspect of the closed-loop system.

In the learner-controlled training condition, strategies for incrementing or decrementing training task difficulty are left completely up to the student. The objective of the training task is specified, but the strategy for achieving the criterion performance is determined solely by the individual.

Procedure

Each subject participated in two experimental sessions. During the first session, subjects were administered the statement of subjects' rights and the pretest battery.

The paper-and-pencil portion of the pretest battery followed the signing of the statement of rights. Each test consisted of two parts and contained its own set of instructions. Each part was scored separately by subtracting the number of incorrect responses from the number of correct responses. The average of the two parts was then calculated, and this score served as the overall test score. Tests scored in this manner included the Identical Pictures Test, the Map Memory Test, and the Cube Comparisons Test. The Embedded Figures Test was administered next. Scores on this test

consisted of the time taken to locate the embedded simple figure within the complex figure. The sum of the times for each of the twelve items comprised the overall EFT score. Lastly, the six 30-second trials on the pursuit rotor were administered. A ten-second rest period followed each trial. The turntable rotated at 60 rpm. Cumulative time on target was recorded for each trial, and the mean time on target averaged across trials served as the overall pursuit rotor score. Subjects were then scheduled for the second session and excused.

Subjects were randomly assigned to one of the three training conditions for the second session. Subjects were seated in the experimental room containing the tracking task apparatus. While adapting to the room's low illuminance level, subjects listened to a set of tape recorded instructions appropriate for their assigned training condition. After answering questions, the experimenter initiated the training task. The experimenter remained in the experimental room for the duration of the first trial, answering any subject inquiries. The experimenter then retired to an adjacent room containing the laboratory minicomputer interface. If a subject failed to exit from the training task in six trials, the experimenter again entered the experimental room to answer any possible questions. The experimenter then returned to the adjacent room unti the training task was completed (either by exiting within the fifteen trials allotted or by manual intervention). If a subject failed to exit within the allotted

5 trials, that subject was paid and excused. Only subjects who were trained to criterion were used to generate the regression equations. Thus, it was necessary to run additional subjects to achieve the full compliment of 90 subjects.

A short rest period followed the training task. Subjects then attended to the transfer task instructions, after which questions were again entertained. The transfer task was then initiated by the experimenter. After the seven-minute transfer task, subjects were paid and excused.

Results will be reported in terms of the training data and the transfer data obtained. The Statistical Analysis System's (SAS) STEPWISE procedure was used to generate the regression equations predicting training time for each of the three training conditions (Barr, Goodnight, Sall, and Helwig, 1976). The final step of the STEPWISE procedure was used as the criterion for choice of the predictive equation. The same procedure was used in generating equations predicting mean rms vecto tracking error (transfer task performance). The SAS ANOVA procedure was used to perform the analyses of variance on training time and transfer performance.

Training data. The regression equations predicting training time are presented in Table 5. First, an overall equation for each training condition was generated. This equation included all subjects trained under a certain strategy (both male and female), thus the variable of sex was added to the predictors. In the equations for both the fixed-difficulty and the learner-controlled conditions, sex proved to be the most heavily weighted predictor.

Next, regression equations based on the sex of the subject were generated for each training condition. In general, these equations did not account for a greater proportion of variance than the overall equations for each training condition. In fact, in no case were the equations able to account for even 50% of the variance. It should be noted that significant

Table 5. Regression Equations for Training Time by Training Condition

SAMPLE	R^2	EQUATION	p
Fixed Difficulty			
Overall	.25	TT = 822.93 + 351.18 (SX) − 50.65 (PR)	.02
Male	.13	TT = 1471.23 − 21.31 (IP)	.19
Female	.14	TT = −644.94 + 46.17 (IP)	.17
Computer-Adapted			
Overall	.06	TT = 1616.16 − 38.57 (PR)	.18
Male	.42	TT = −540.04 + 244.43 (MM) − 77.72 (PR)	.04
Female	.06	TT = 2287.70 − 84.61 (MM)	.37
Learner-Controlled			
Overall	.47	TT = 880.13 + 593.99 (SX) − 59.24 (PR)	.0002
Male	.32	TT = 1737.05 − 84.65 (PR)	.03
Female	.11	TT = 2268.62 − 43.17 (CC)	.22

KEY: TT = Training time; in seconds
      SX = Sex; male or female
      PR = Pursuit rotor; average time on target, in seconds
      IP = Identical Pictures Test; number correct minus number incorrect
      MM = Map Memory Test; number correct minus number incorrect
      CC = Cube Comparisons Test; number correct minus number incorrect

equations could not be obtained for five of the nine samples investigated. This result is in direct conflict with results obtained previously with the two-dimensional pursuit tracking task (Savage et al., 1978; 1979).

Table 6 shows the source table for a two-way analysis of variance conducted on training times. The analysis yielded a significant effect of training condition ($p=.031$) and a significant effect of sex ($p=.0003$). In addition to the significant main effects, a significant sex by training condition interaction was obtained ($p=.054$).

Table 7 lists the means for the training time by training condition and sex. Also presented are the means for training time for the sex by training condition interaction. A Duncan Multiple Range Test yielded a significant difference between fixed-difficulty and computer-adapted training conditions, and between the fixed-difficulty and learner-controlled conditions ($p<.05$). There was no significant difference in training time between the computer-adapted and the learner-controlled training conditions ($p>.05$). No significant difference in training time was yielded for the sex by training condition interaction breakdown. Two results are evident from Table 7. First, it can be seen that males took significantly less time to train than did females. Also, a significant difference exists between the traditional fixed-difficulty training condition and each of the indivdualized training strategies (the computer-adapted and the learner-controlled).

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Table 6. ANOVA Source Table for Training Time

Source	df	SS	F	p
Training Condition	2	2482967.8	3.63	.03
Sex (SX)	1	4821404.4	14.11	.0003
TC x SX	2	2066979.7	3.02	.054
Subjects/TC x SX	84	28702103.7		
TOTAL	89	38073455.6		

Fifteen subjects were unable to be trained to criterion in the allotted fifteen trials. In the fixed-difficulty condition, two females and one male failed to exit. Six females and one male failed to exit the computer-adapted condition, and four females and one male were unable to train to criterion in the learner-controlled training condition. Data from these subjects were not used in generating the regression equations reported in this thesis, since criterion level of performance was never achieved by these subjects. Additional subjects were run in order to obtain the appropriate number of subjects in each training condition. A x^2 analysis was conducted to determine whether subjects who were unable to be trained to criterion occurred randomly between training conditions. The x^2 demonstrated that subjects not exiting the training task occurred randomly between training conditions, $x^2_{(2)} = 1.6$, $p > .05$.

Table 7.   Training Time Means for the Training Condition and Sex
Main Effects and the SX x TC Interaction

Training Condition	Mean
Fixed-Difficulty	949.92
Computer-Adapted	1316.72
Learner-Controlled	1285.78

Sex	Mean
Male	952.69
Female	1415.60

SX x TC	Mean
Fixed Male	734.49
Fixed Female	1165.35
Adaptive Male	1262.34
Adaptive Female	1371.10
Learner-Controlled Male	861.23
Learner-Controlled Female	1710.33

Four male subjects exited within the first trial in the
fixed-difficulty training condition.   Data from these subjects
were not used in generating the regression equations since the
innate tracking ability of these males was at such a level that
it was assumed that training did not take place.

Transfer data. The transfer tracking errors were averaged across the three levels of difficulty of tracking and the averaged rms error scores were used in the data analysis. The regression equations predicting mean rms vector tracking error (transfer task performance) are presented in Table 8. Again, the proportion of variance accounted for by these equations is consistently low, although significant equations were obtained in all cases.

Table 9 gives the source table for an analysis of variance conducted on mean rms vector tracking error (transfer task performance). The ANOVA yielded a significant effect of sex ($p=.02$), and a significant effect of training condition ($p=.03$). Male subjects had lower tracking errors in transfer than female subjects. Duncan Multiple Range Test yielded no significant difference between the fixed-difficulty and computer-adapted conditions, but both of these conditions had significantly less tracking error than the learner-controlled condition ($p<.05$). Table 10 lists the mean rms vector tracking error by training condition and be sex. The effect of level of difficulty was also significant ($p=.0001$), thus demonstrating that the three levels of difficulty in transfer task performance actually represent different skill levels.

Table 8. Regression Equations Predicting Mean RMS Vector Tracking Error by Training Condition

SAMPLE	R^2	EQUATION	p
Fixed Difficulty			
Overall	.20	TR = .1195 − .0009 (IP) + .0116 (SX)	.05
Male	.51	TR = .1041 + .00004 (EFT) − .0014 (PR)	.01
Female	.27	TR = .1808 − .0018 (IP)	.05
Computer-Adapted			
Overall	.21	TR = .1230 − .0026 (PR)	.01
Male	.19	TR = .1084 − .0014 (PR)	.11
Female	.25	TR = .1430 − .0053 (PR)	.06
Learner-Controlled			
Overall	.26	TR = .0710 + .0019 (IP) − .0032 (PR)	.05
Male	.28	TR = .1686 − .0055 (PR)	.04
Female	.48	TR = −.0016 + .0023 (IP) + .0002 (EFT)	.02

KEY: TR = Transfer performance; mean RMS vector tracking error
SX = Sex; male or female
CC = Cube Comparisons Test; number correct minus number incorrect
EFT= Embedded Figures Test; time to identify, in seconds
IP = Identical Pictures Test; number correct minus number incorrect
PR = Pursuit rotor; cumulative time on target

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Table 9. ANOVA Source Table for Mean rms Vector Tracking Error

Source	df	SS	F	p
Between Subject				
Training Condition	2	.014	3.51	.03
Sex	1	.011	5.59	.02
TX x SX	2	.011	0.16	.85
Subjects/TX x SX	84	.171		
Within Subject				
Level of Difficulty	2	.115	151.04	.0001
LOD x TX	4	.000	0.06	.99
LOD x SX	2	.000	1.20	.31
LOD x TC x SX	4	.002	1.10	.36
LOD x Subjects/TC x SX		168		
TOTAL	269	.378		

Table 10. Means for Transfer Performance by Training Condition and Sex

Training Condition	Mean
Fixed-Difficulty	.105
Computer-Adapted	.103
Learner-Controlled	.119

Sex	Mean
Male	.102
Female	.115

DISCUSSION AND CONCLUSIONS

The most striking result of this research was the extremely limited predictive ability of the regression equations predicting training time for the three training conditions. This result is inconsistent with that obtained by Savage, Williges, and Williges (1978), in which consistently high proportions of variance were accounted for by regression equations predicting training time for both a fixed-difficulty and a computer-adapted training condition.

Several factors may have contributed to this limited predictive ability. A somewhat different software package was used to generate the tracking task for this experiment. The primary difference was in the generation of the position of the forcing function symbol "X". This software used four independent functions to determine the random movement of the "X" symbol, whereas the Savage et al. software used three. A sliding average error was used in the computer-adapted training condition to calculate and present the position of the "ACCURACY" feedback bar. This computation integrates time and distance off-target, thus providing a smoother movement of the feedback bar and a more accurate representation of the subject's performance. This indirectly affects the adaptation of the task to the subject's performance. In addition, the control system dynamics were changed to pure acceleration dynamics. Although inherently harder to control, task parameters were adjusted in order to obtain a task as similar

to that of Savage et al. as possible. It can be seen, then, that due to these changes in both software and control system dynamics, the tracking task was not identical to that previously used. Although the task appeared very similar, an exact replication was not possible. It must be noted, however, that although these coefficients of multiple determination seem low when compared to those obtained by Savage et al., they are relatively consistent with results reported in the literature in the area of behavioral prediction.

A diversity of results is also evident when one compares the equations predicting training time for the learner-controlled strategy with that obtained in the preliminary study. The equation for the preliminary study accounted for 80% of the variance, whereas the obtained equations could only account for 47% of the variance at best. One factor which could account for this difference was the number of training trials administered in the preliminary study. Since the preliminary study was conducted to test the functioning of the learner-controlled training apparatus and to observe the behavior of the predictor variables, a maximum of only twelve trials was given. Subjects failing to train to criterion within twelve trials were excused. Should these subjects have been allowed fifteen trials for training, different results might have been obtained.

An interesting observation is that the proportions of variance accounted for by the equations were relatively consistent with those obtained in the joint effort research

described in the introductory section (refer to Table 1). It would seem that application of the multiple regression approach to capitalizing on individual differences is task specific. The tasks of interest in both this and the joint effort studies were different from that used by Savage et al. in the development of the methodology. It may be that the success of the multiple-regression approach to individualized instruction is contingent upon the use of different predictor batteries relative to the specific task of interest. Although the joint effort is an extreme case of application of the methodology, this aspect of task specificity could limit the widespread feasibility of this methodology. If different individual differences must be measured for each task of interest, the use of these individual differences in a multiple-regression methodology may not be cost or time effective. This thesis, therefore, has served to delineate the boundaries of appliction of the multiple-regression approach to capitalizing on individual differences in motor skills training.

The number of subjects failing to train to criterion constituted 14% of the total number of subjects run. This figure seems quite high, but several aspects of this phenomenon require clarification. 80% of those not training to criterion were females. The sex difference previously demonstrated on the two-dimensional pursuit tracking task by Savage et al. may have been acdentuated by the changes in the task. 83% of the females not exiting were trained under the computer-adapted and learner-controlled training strategies. This result could

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suggest implications for the use of individualized approaches with females in the training of motor skills.

Several results do support previous research involving the two-dimensional pursuit tracking task. A pronounced sex effect was againdemonstrated by this study, with males performing significantly better than females on this particular motor skill task. This effect has been documented previously (Savage, Williges, and Williges, 1978, 1979, and Williges, Williges, and Savage, 1978). The individualized strategies, i.e., the computer-adapted and learner-controlled training conditions, required a longer training time. This effect was also reported by Cote (1979), with the adaptive training condition requiring more training time than the fixed-difficulty condition on both studies. A tradeoff occurs, however, when one considers transfer of training performance as the criterion of interest. This thesis research demonstrated that the computer-adapted training condition provided for better transfer of training performance than did the traditional fixed-difficulty strategy. This result was also documented by Cote (1979).

It is interesting to note that the best prediction of training time occurred with the learner-controlled training strategy. It would seem logical, however, that a methodology seeking to capitalize on individual differences would work best with a training strategy contingent upon the individual. It was unexpected that this training condition would yield the poorest transfer performance. The fact that the subject had to

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control task difficulty (thus occupying both hands) could have made a significant addition to the training task, thus making the training and transfer dissimilar enough t cause this decrement in performance.

Savage, Williges, and Williges (1979) were able to use the multiple regression approach to assign subjects to a training strategy. This research was unable to generate regression equations which were reliable enough to use in a subsequent assignment procedure. Again, this may be attributed to the specificity of the methodology for the task of interest. Therefore, the utility of the approach could only be demonstrated for the task for which it was developed, and not for that used in this thesis research.

Conclusion

Several findings may suggest implications for further research. No significant differences were demonstrated between the training times of the individualized training strategies (between the computer-adapted and learner-controlled conditions). There was a significant difference, however, between each of the individualized approaches and the traditional fixed-difficulty approach to motor skills training. Although requiring a longer training time, the computer-adapted training condition provided for better transfer of training performance. This suggests a tradeoff which could hold implications for both cost and time considerations in real-world training systems.

Use of the multiple-regression approach to individualized instruction has yielded inconsistent results. It may be that the methodology is task specific. This raises questions as to the feasibility and time/cost effectiveness of the individual differences approach. More research is needed to define the utility of such an approach. This thesis has served to outline the boundaries for application of the multiple-regression approach to capitalizing on individual differences in motor skills training.

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