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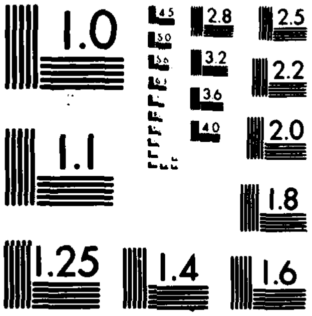
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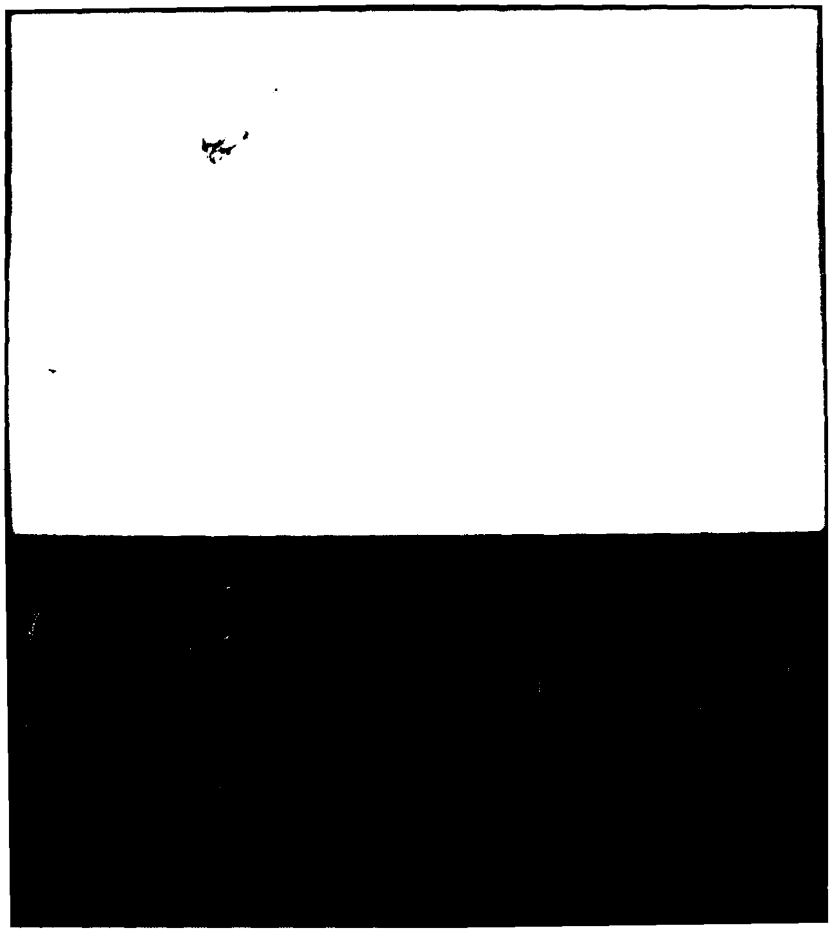

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The goal of this programmatic research effort was to investigate the ramifications of both micromodels and macromodels in individualizing motor skills training. Specifically, the research conducted during 1 October 1978 to 30 September 1979 dealt with the use of feedback in adaptive training, the extensions of regression approaches to training group assignment, and the evaluation of population differences.

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AUTOMATED MOTOR SKILLS TRAINING OPTIMIZED FOR INDIVIDUAL DIFFERENCES

1 October 1978 - 30 September 1979

by

Beverly H. Williges and Robert C. Williges

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November 1979

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STATEMENT OF WORK

As the fuel situation worsens, the Air Force will need to maximize the effectiveness of computer-based synthetic flight training. The training of motor skills in synthetic trainers is a critical element of flight training because of the new tasks pilots may be called upon to perform in future warfare. 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 major difficulty in motor skills training is the large intersubject variability resulting when only one fixed training procedure is employed. However, modern computer technology provides the capability to process large amounts of continually varying data such that the instructional environment could be adapted to the learning characteristics of the individual student. By using the computer inherent in the design of synthetic flight trainers, the development of effective ground-based training programs for individual students in pilot training should be possible.

Individualized training involves adapting instructional practices to individual requirements either by optimizing the instruction sequence or by selecting appropriate training alternatives for individual students. Traditionally motor skills training has employed a fixed-difficulty strategy in which students are immediately exposed to the criterion level of task difficulty and student error decreases as training progresses. Unfortunately, this strategy has no provision for individual differences in prior experience, rate of learning, or learning style. Therefore, the training task may be too easy at times for some individuals and too difficult at times for others, resulting in an inefficient use of training time.

Two general approaches to individualizing motor skills training are possible by considering micromodels and macromodels. The micromodel approach assumes that each student follows his or her unique learning model through training. One example is adaptive motor skills training. In adaptive motor skills training 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 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 an adaptive training system as requiring 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 usual approach taken in adaptive procedures is to use a single logic system. Even though this one logic system provides a variety of individual task difficulty profiles, it may not provide enough flexibility for various styles of information processing.

The macromodel 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. The macromodel approach has been pursued by Cronbach and his colleagues (Cronbach and Snow, 1977) with only limited success. The difficulty arises from the inability to specify aptitude-treatment interactions and to associate these interactions with specific types of training.

An alternative macromodel approach avoids the need to specify underlying aptitude-treatment interactions by using regression equations to predict individual performance for each available training type. A comparison of predicted performance under each training type determines the optimal training condition for the student. No categorizations of student learning styles or training alternatives are necessary.

The goal of this programmatic research effort was to investigate the ramifications of both micromodels and macromodels in individualizing motor skills training. Specifically, during this year's effort, additional research was conducted on the use of feedback in adaptive training, the extension of regression approaches to training group assignment, and the evaluation of subject population differences.

Adaptive Training: A Micromodel

One important issue in adaptive training deals with the role of augmented feedback. Bilodeau and Bilodeau (1961) state that "studies of feedback...show it to be strongest, most important variable controlling performance and learning." However, the Kelley (1969) adaptive logic system minimizes the usefulness of intrinsic task feedback. By manipulating task difficulty based on performance, relatively constant level of error is maintained over time. Consequently, the student sees no progress in terms of error and may need augmented feedback in terms of the level of task difficulty. Although he never evaluated his position experimentally, Kelley contends that augmented feedback in terms of task difficulty is essential in adaptive training.

Norman (1973) compared the use of a task difficulty meter with the use of no feedback in adaptive training and found some savings in learning a transfer task when the task difficulty meter was used. However, the two experimental conditions compared were from two separate studies and involved different subject pools. In Experiment I (feedback condition) college students and recruits from the Navy Training Center were involved. In Experiment II (no feedback condition) only college students were used as subjects. This methodological problem permits only tentative conclusions to be drawn from the results.

A more recent study by Cote, Williges, and Williges (1978) indicated that augmented feedback during training in terms of task difficulty and accuracy of performance had no effect on learning a two-dimensional pursuit tracking task using either a fixed difficulty or an adaptive training strategy. Certainly if subjects used the visual feedback, an increase in visual workload occurred. Because the visual load in the training task was inherently high, it is unclear whether visual feedback was unnecessary or unused.

High visual workload is common with many motor skills, such as controlling an aircraft or an automobile. Logically feedback might be more useful if provided through a channel other than visual. For example, Gilson and Ventola (1976) have successfully used tactual augmented feedback to present information concerning the flight path to pilots during approach and landing operations.

However, vision appears to be the dominant modality in motor learning. Disagreement exists among motor learning theorists concerning the value of feedback in other sense modalities. The current research explored the usefulness of auditory augmented feedback in adaptive motor skills training. Specifically, the effectiveness of visual, auditory, auditory and visual, and no augmented feedback were compared.

Training Assignment: A Macromodel

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 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 of the training situation for the student).

To determine the appropriateness of the training situation for a specific student a model, such as a regression equation, may be used. (Kaskowitz and Suppes, 1978, have suggested that a regression equation may be considered to be a mathematical model in the sense that a linear relationship between time to train and certain independent variables is hypothesized.) Using regression equations to predict time to complete a course on stock control and accounting, Wagner, Behringer, and Pattie (1973) found that grouping students according to mode of instruction (audio-visual or programmed instructions) improved prediction. The improvement in prediction suggests that training type interacted with some individual characteristic of the students. It follows that a comparison of predicted scores associated with the various training types might yield an optimal training assignment.

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) reports 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 reported when regression modeling was used.

The current research at VPI extends the regression model approach of training group assignment to the perceptual-motor learning domain. Specifically, each student was assigned to a training strategy on the basis of predicted scores from baseline regression models of training time-to-exit. Students were matched (shorter predicted time), mismatched (longer predicted time), or randomly assigned to fixed-difficulty or adaptive training to learn a two-dimensional pursuit tracking task.

<u>Subject population validation</u>. One critical element in any research is the selection of an appropriate subject population. The current set of regression models for training group assignment has been developed using civilian university students as subjects. Both men and women were involved. These students are in the same age range and probably possess many characteristics similar to young military officers. However, a comparison of the performance of this civilian population with that of an appropriate military population would be useful to establish the validity of the regression models and the regression approach to individualized instruction in flight training. In

addition, a comparison of any differences in the reliable predictors for males and females would be useful.

With these goals a joint research project between the Human Factors Laboratory, Virginia Polytechnic Institute and State University, and the Department of Behavioral Science and Leadership, U.S. Air Force Academy, was conducted. A series of pretests, including the tests used to generate the original regression models, were given to a set of VPI students and a set of Air Force Academy cadets. Scores on these tests were used to generate new multiple regression prediction equations predicting post-training performance on a desk-top flight trainer.

STATUS OF THE RESEARCH

Research Tasks

Two general tasks were used in the research studies completed in the 1978-79 contract year. The first task is a two-dimensional pursuit tracking task generated by a PDP 11/10 digital computer interfaced with a Tektronix 4014-1 cathode ray tube display and a Measurement Systems Model 435 isometric control stick. The second type of task uses an ATC-610 desk-top flight trainer.

In the tracking studies each student completes a series of 3-minute tracking trials to learn a two-dimensional task in which random functions are used to determine the coordinates of the forcing function symbol (X) on the display. The control output (O) is generated using inputs from the analog controller. Task difficulty can be manipulated automatically by the computer using a linear optimization model, maintained at a fixed level of difficulty, or controlled by the student. Integrated absolute tracking error is recorded automatically by the computer. Figure 1 shows the version of this task where dynamic, augmented feedback in terms of task difficulty and tracking accuracy is presented in addition to the forcing function and controller symbols. Exit criterion is obtained when the student maintains exit criterion task difficulty and acceptable accuracy for a specified period of time (usually 20 seconds). Following training and a short rest period, each subject completes a transfer task in which no augmented feedback is provided, and task difficulty is changed periodically. Three levels of difficulty are used: the same as exit criterion in training, more difficult than exit criterion, and less difficult than exit criterion. All software for the tracking task was written by John E. Evans, III. (Figure 2 illustrates the software configuration for the tracking task.)

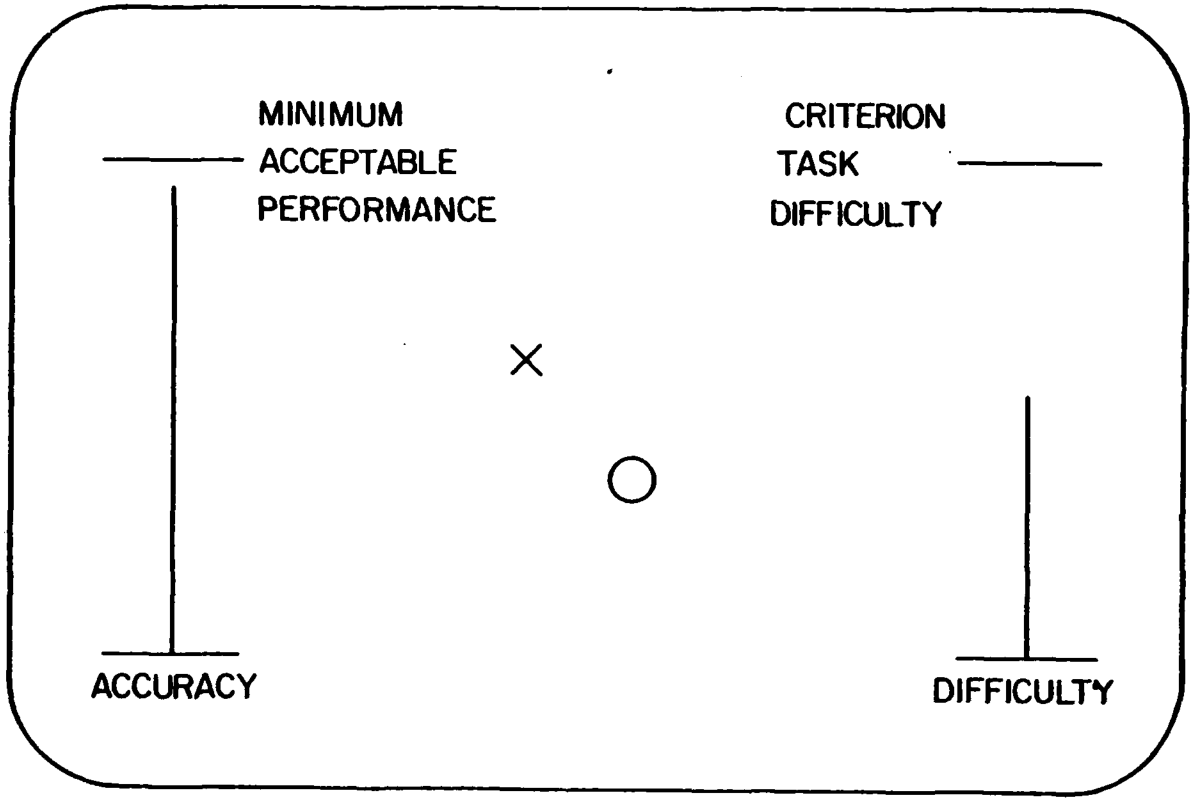

Figure 1. Two-dimensional pursuit tracking task with forcing function symbol, controlled element, and augmented feedback indicators.

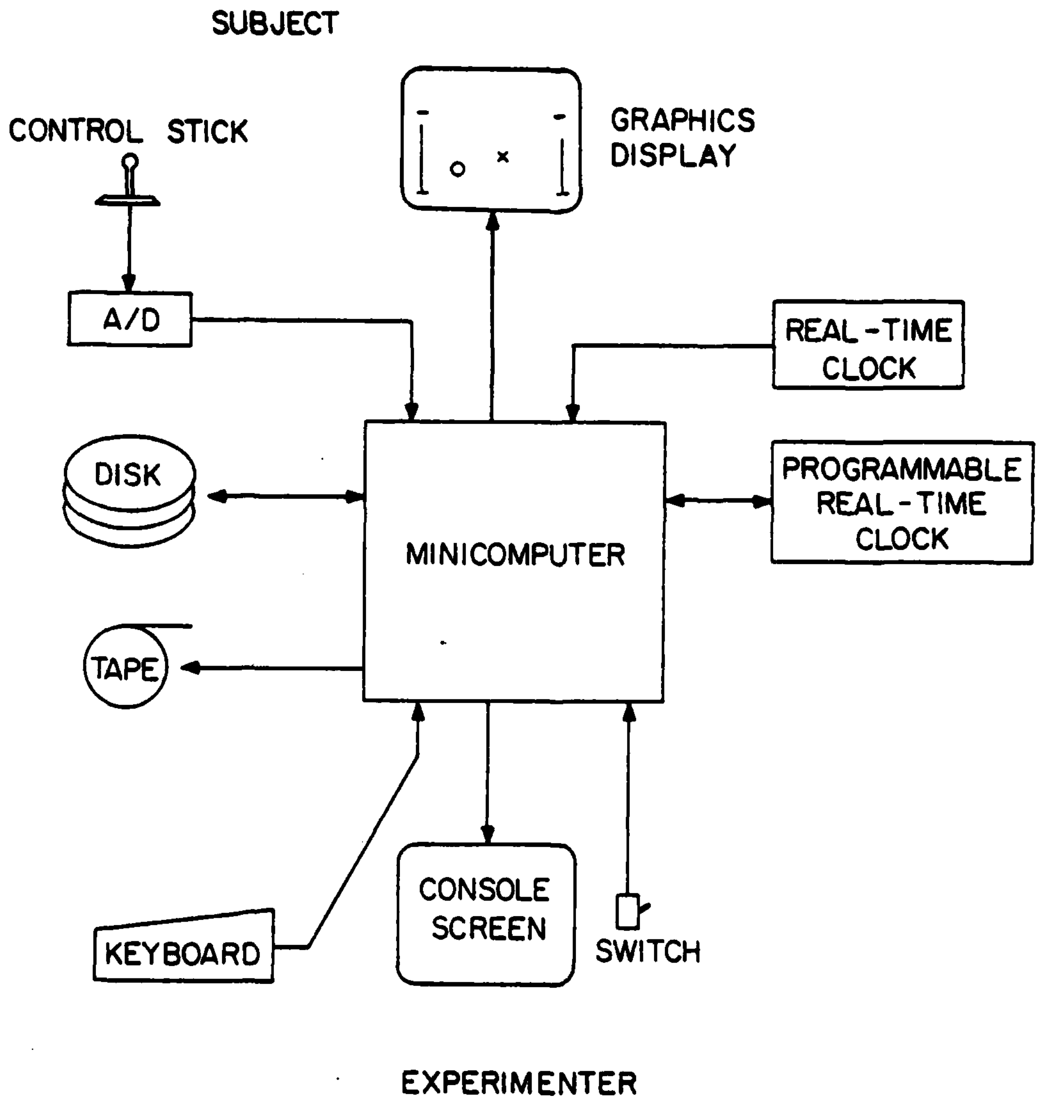

Figure 2. Software configuration for the two-dimensional pursuit tracking task developed by John E. Evans, III.

The flight task used in the population comparison research involved a desktop trainer equipped with the flight instruments normally associated with light aircraft. Figure 3 illustrates the instrument panel of this trainer. Students received approximately 40 minutes of training via audio cassette and color photographs on basic flight controls and instruments. Two practice trials on each manuever were given. During the first practice trial the instructor could intervene if the student did not appear to understand the manuever. Students were tested twice on each of four manuevers, once in smooth air and once in rough air. Simulated turbulence was introduced through an electrical signal which was reflected in the aircraft instruments. The turbulence control is a six-position switch labeled OFF and 1-5. The switch was OFF for smooth air conditions and set at position 2 for rough-air conditions. The tasks in the trainer were climb on a heading at the 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 180 degrees. The trainer was trimmed for level flight, and students were not required to control airspeed, fuel mixture, or manifold pressure. As a result the task was quite similar to a multidimensional tracking task.

Augmented Feedback in Adaptive Training

To examine the effects of various forms of augmented feedback 96 male subjects were taught a two-dimensional pursuit tracking task using either a fixed-difficulty or adaptive training procedure. Subjects in each training procedure were placed in one of four feedback conditions: (1) auditory off-course feedback only, (2) visual off-course feedback only, (3) auditory and visual off-course feedback, or (4) no augmented feedback. Subjects trained adaptively also received feedback in terms of task difficulty changes. All

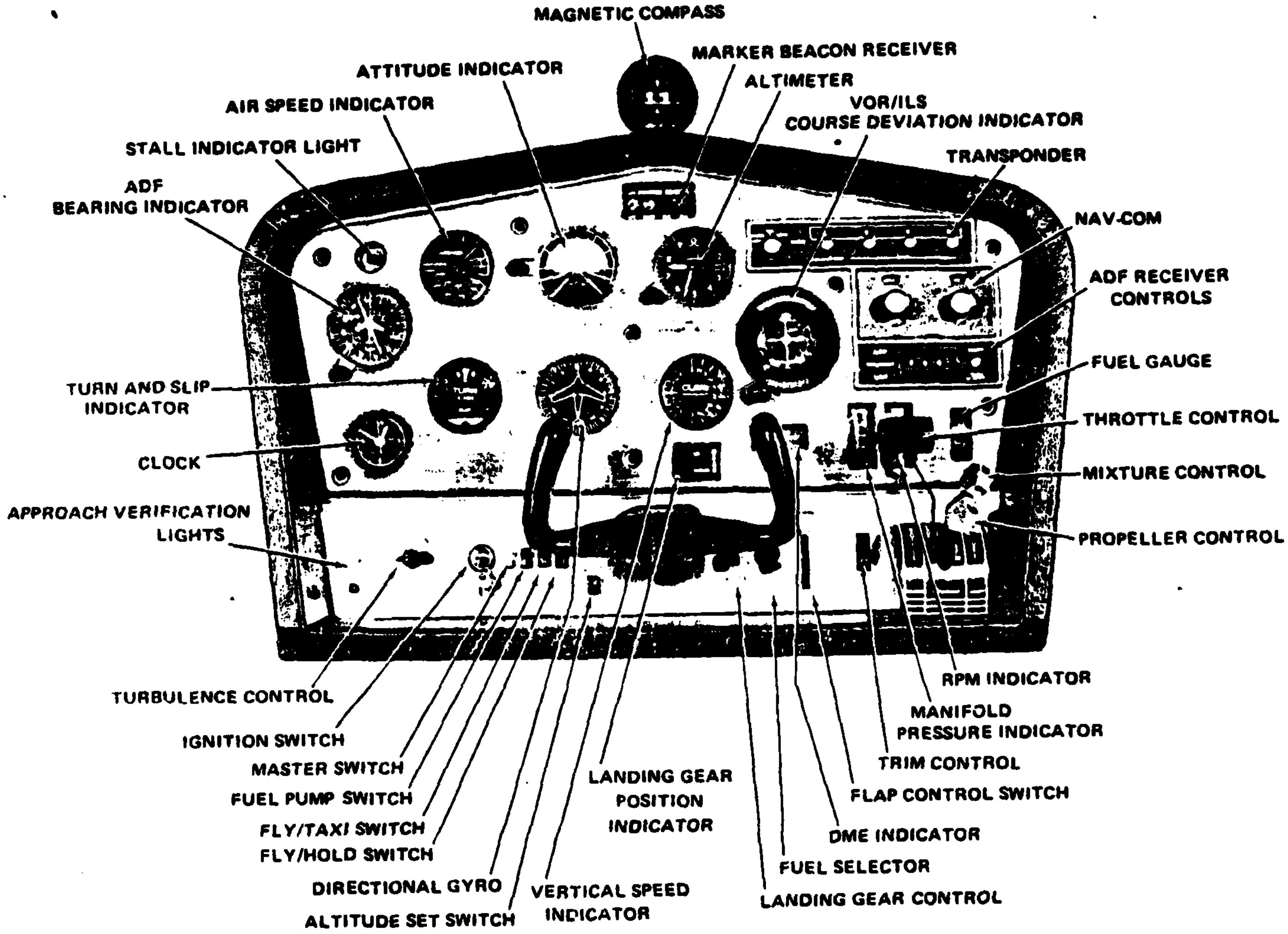

Figure 3. ATC-610 personal flight trainer instrument panel.

subjects received a 6-minute, no-feedback transfer task similar to the transfer task used in previous studies. Three levels of task difficulty were presented, and the order of presentation of the three levels of task difficulty was counterbalanced across subjects. The complete experimental design is given in Figure 4.

Visual feedback was provided by bar graphs located on either side of the tracking area. Auditory feedback was provided through a loud speaker. Two distinct tones varying from a continuous tone to silence (criterion level) were used to present task difficulty and tracking accuracy information.

No reliable effect due to feedback condition or training procedure was reflected in training time-to-exit data. However, subjects trained adaptively performed significantly better ($p=.025$) in transfer than those subjects trained in the fixed-difficulty situation. This may have been partially the result of students trained adaptively having received practice at various levels of task difficulty during training.

These results, as well as the results of the previous research (Cote, Williges, Williges, 1978), 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 an extended time period, and off-track feedback may be effective in enhancing performance in adaptive systems lacking clearly discernible intrinsic feedback.

The results of this study on visual and auditory feedback in adaptive skill training are summarized in the following report:

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

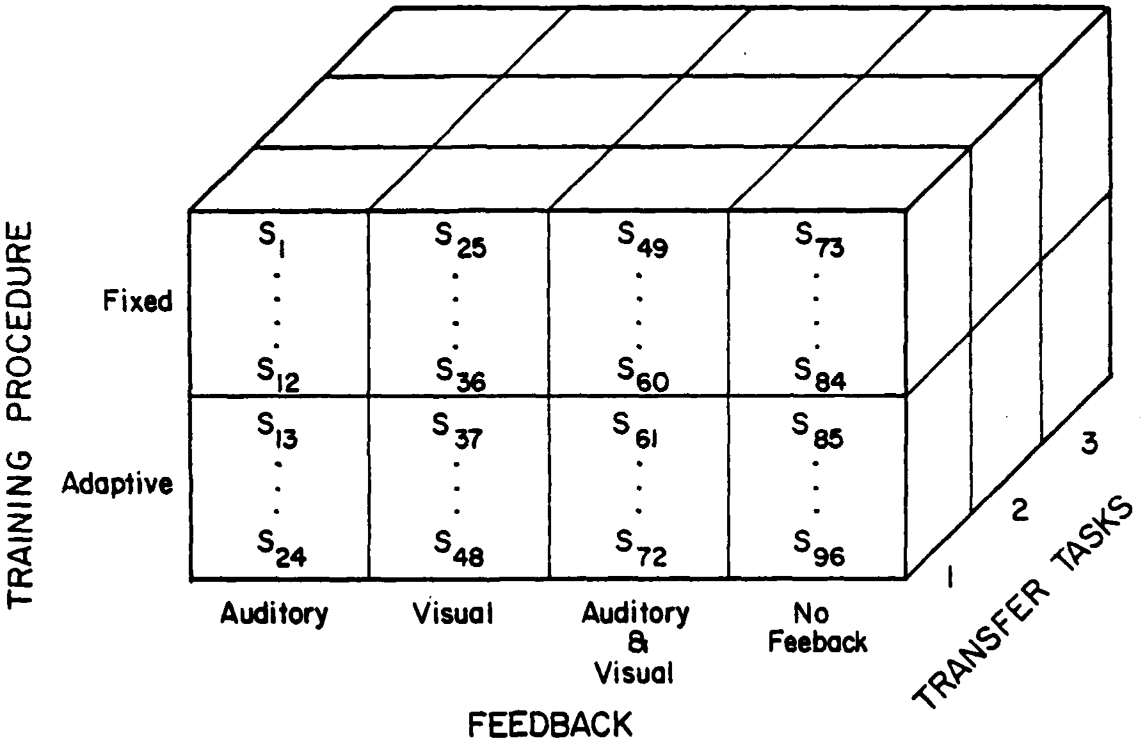

Figure 4. Experimental design for the evaluation of augmented feedback in adaptive motor skills training.

Training Group Assignment

To study the efficacy of the regression approach to training group assignment, multiple regression equations were used to assign 120 students to either fixed-difficulty or adaptive training strategies for learning the two-dimensional pursuit tracking task. Students were either matched (shorter predicted training time), mismatched (longer predicted training time), or randomly assigned to a training type. An equal number of male and female students were used in each assignment procedure by training type combination. Figure 5 depicts the factorial design used in this study.

Previously a double cross-validation procedure had been used to validate the regression equations predicting time to learn the tracking task because the coefficients of multiple determination were consistently high, the two samples were combined and new equations were generated. These combined sample equations were employed in the present study for training group assignment (see Table 1). For details on the pretest battery and validation procedures see Savage, Williges, and Williges (1978).

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, $F(1,108)=40.57, p<.0001$. Matched subjects required significantly less time to exit than either random or mismatched subjects, and males required significantly less training than females. There was no reliable difference between training alternatives ($p=.246$).

Use of the regression equations to predict optimal training type resulted in savings of 47% of training time over random assignment and 53% over mismatched assignment. Variance in training time was reduced approximately 40% by optimizing training group assignment. Table 2 summarizes the reliable effects from the analysis of training time.

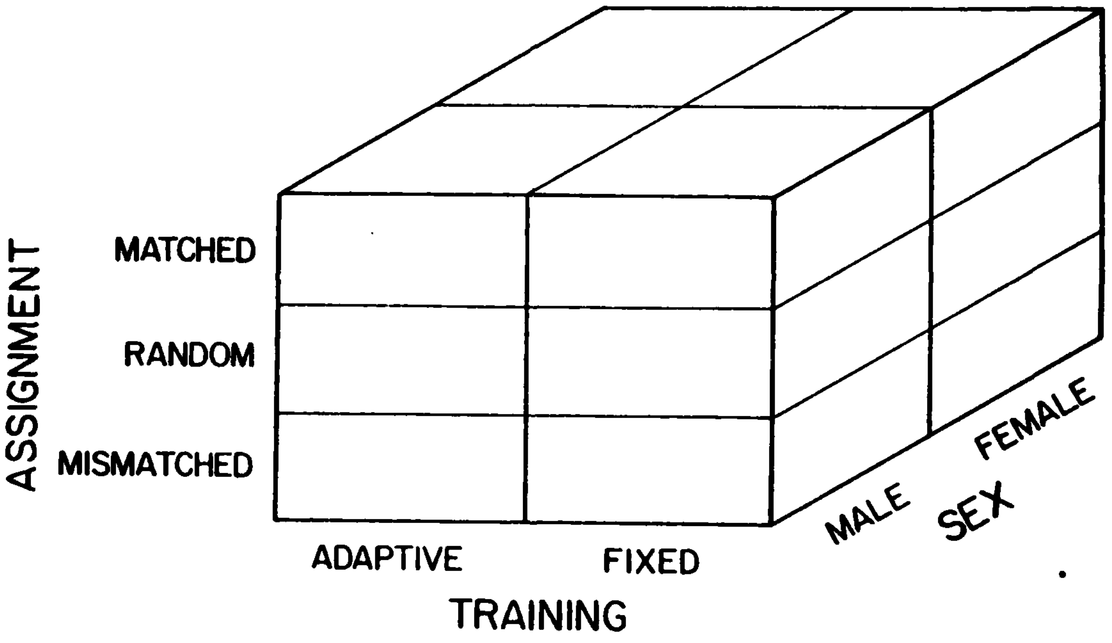

Figure 5. Experimental design for the study of training group assignment.

TABLE 1

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

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Fixed-Difficulty Training

$$TE_{FD} = -897.89 + 1.67\,EF + 45.49\,IP - 32.66\,CC$$

$n = 48$

$R^2 = .632$

$R_S^2 = .607$

Adaptive Training

$$TE_A = 2641.65 + 1.72\,EF - 256.90\,MM + 516.42\,SX$$

$n = 51$

$R^2 = .756$

$R_S^2 = .740$

EF = Embedded Figures Test (Witkin, Oltman, and Raskin, 1971)
IP = Identical Pictures Test
CC = Cube Comparison Test
MM = Map Memory Test
(Ekstrom, French, Harman, and Dermen, 1976)
SX = Sex of Student

TABLE 2

Summary Statistics for Training Time-to-Exit (min) in the Training Group Selection Study

Effect	$\bar{X}$	σ
Training Type		
Fixed-Difficulty	15.6	10.1
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

These data strongly support the use of regression equations to optimize training group assignment. The optimization procedure resulted in savings in training time and a reduction in variance among students. Interestingly, no overall difference in training time between fixed-difficulty and adaptive training was noted. If the study had employed only random assignment, one might have erroneously concluded that no advantage is to be gained in providing alternative training conditions.

To facilitate implementation in operational training systems, research is warranted to examine regression optimization with additional types of predictors, training procedures, and more complex training tasks. Guidelines for selection of viable predictors are particularly critical. The experience with the Advanced Instructional System vividly portrays the complexity of implementing innovative training programs. However, if the computer is ever to provide real value to training systems, the challenge of the operational training system must be conquered.

This research is summarized in the following papers:

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.

Williges, B. H., Williges, R. C., and Savage, R. E. Predicting optimal training group assignment. Proceedings of the Human Factors Society 23rd annual meeting, Boston, Massachusetts, October, 1979, 295-299.

Joint Air Force Academy/VPI Research

The second research project during 1978-79 involving regression procedures was a joint effort with the U.S. Air Force Academy, Department of Behavioral Sciences and Leadership, and was coordinated by Lt. Col. Jefferson M. Koonce at the Air Force Academy and by Prof. Robert C. Williges at

Virginia Polytechnic Institute. The purpose of the research was to compare the equations of civilian university students with Air Force cadets and of male students with female students to predict performance on a real-world flight task. 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 tasks. (See Savage, 1979, for a complete description of each test.) The information processing tests used were comparable to the tests on 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 are currently under consideration by the Air Force as pilot selection devices which feature 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 6. 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 7. Pretesting required two 50-minute sessions.

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. Details on the flight training and testing session are given previously. The training-testing package was developed by Beverly H. Williges and was largely based upon the Automated Pilot Aptitude Measurement System (APAMS) developed by McDonnell Douglas Corporation for the Air Force Human Resources Laboratory.

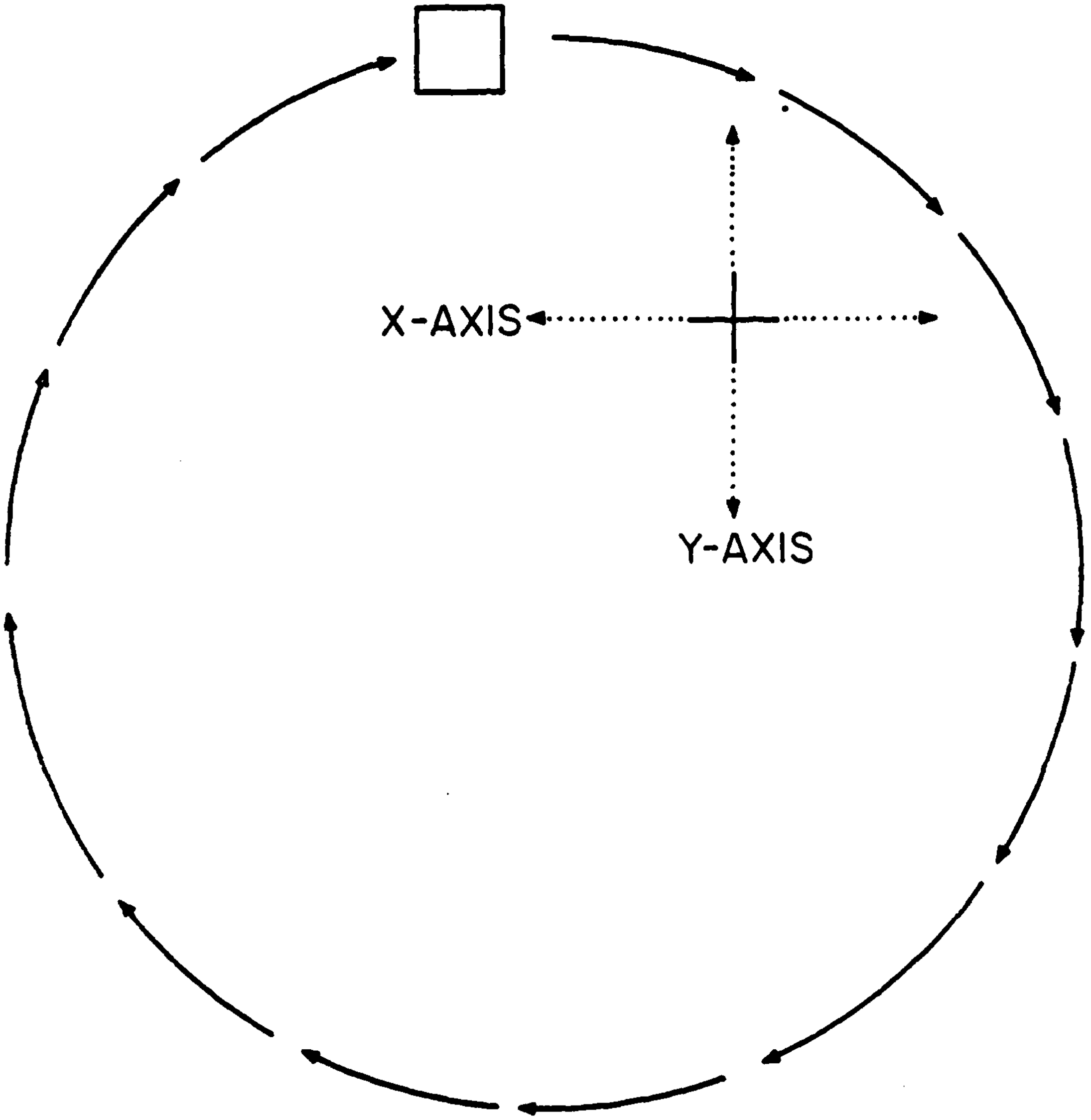


Figure 6. Display for two-hand coordination task on the PTD. (Test 1).

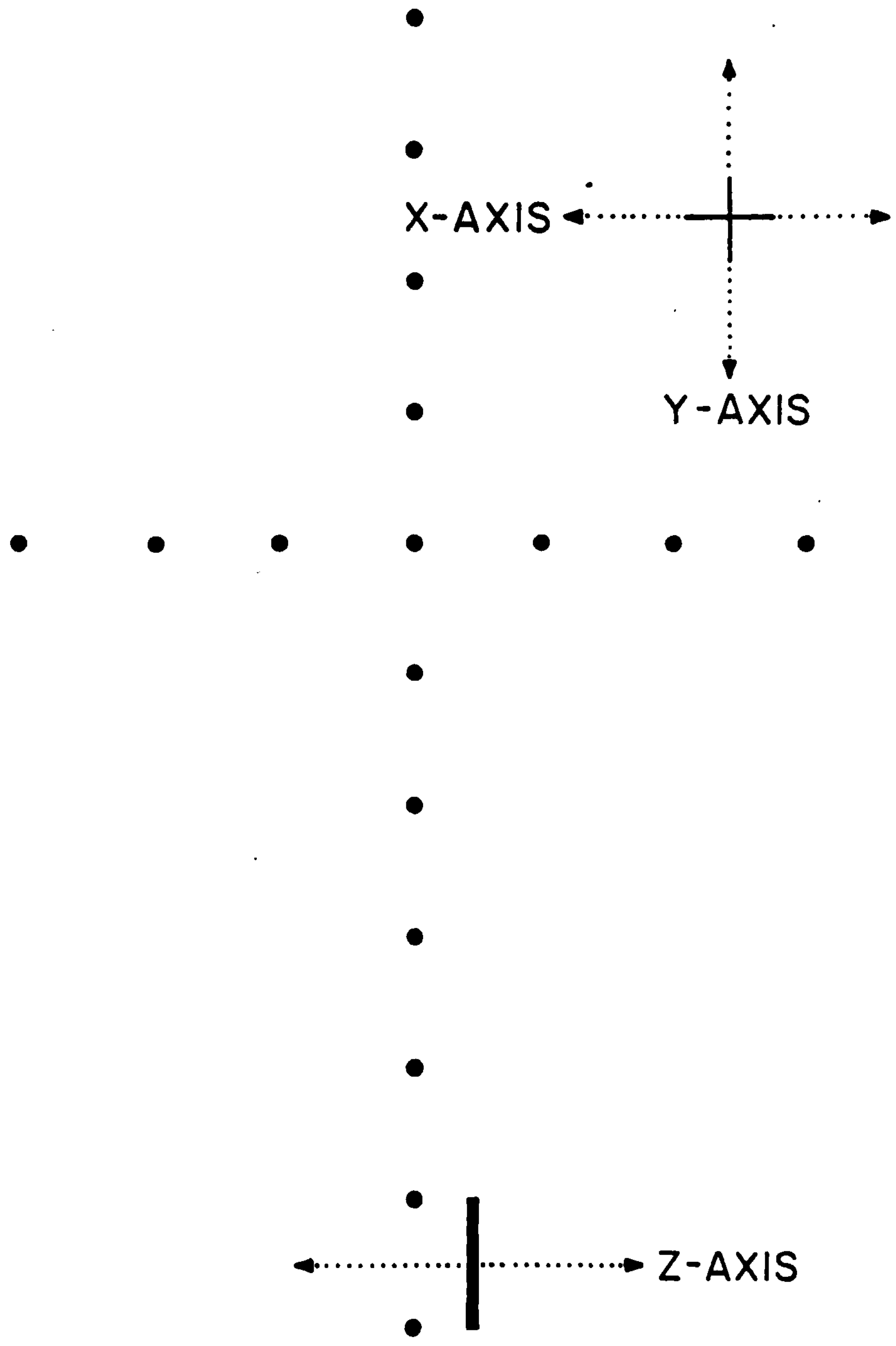


Figure 7. Test 2 on the PTD including the two-dimensional compensatory tracking task controlled by a two-axis joystick and the one-dimensional compensatory tracking task (z-axis) controlled by foot pedals.

Scoring on the flight test was facilitated by an objective pilot performance rating booklet developed by Lt. Col. Koonce. A sample page from the booklet appears as Figure 8. The booklet was similar to the rating scales successfully used by Koonce (1974) to measure performance on instrument flight manuevers.

A total of two hundred students received the pretests, flight training, and flight tests. Previous flight experience of subjects varied from none to private certificates. However, no cadets had received undergraduate pilot training, and average flight experience among VPI students versus cadets was approximately equal.

Because approximately 600 hours of experimental time were required over a short period of time, various people served as experimenters. At VPI pretesting was administered by Richard E. Becker, Ricky E. Savage, David O. Cote, and Beverly H. Williges; all flight training, testing, and rating was performed by Richard E. Becker.

At the Air Force Academy, pretesting, training, testing, and rating was conducted by Lt. Col. Jefferson M. Koonce, Richard E. Becker, Lt. Col. Gene A. Berry, and Charles R. Beaver. Interrater reliability for the flight tasks at the Air Force Academy was .893.

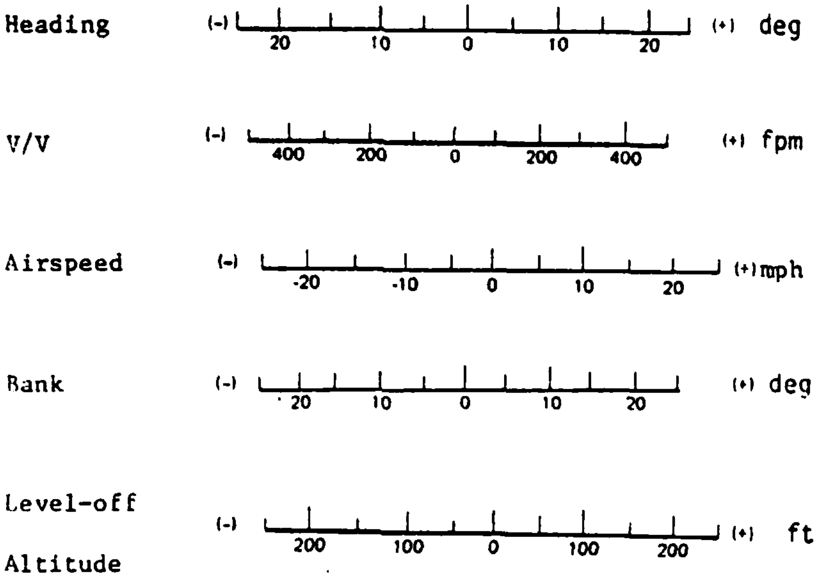
All statistical analyses were conducted at VPI using the University's MVS batch services on twin IBM System/370 Model. The statistical package used was SAS 76 by Barr, Goodnight, Sall, and Helwig. Richard E. Becker and Scott R. Stacey conducted the analyses under the direction of Lt. Col. Koonce and Dr. Williges.

Two-factor analyses of variance (ANOVA) were conducted on all pretest data to determine the effects of sex and institution. In the original pretest battery there were no reliable differences due to institution.

Descend from 2000 ft. to 1000 ft. Heading = 090 deg.

V/V = 500 fpm., Airspeed = 160 mph. Level off at 1000 ft.

Once descent is begun:



(when V/V goes to or through zero)

TEST 3 DESCEND 1000 Ft.

Figure 8. Sample page from rating scale booklet used to score performance on the ATC manuevers.

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=.0001), 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 ANOVA on ATC flight test ratings revealed reliable main effects of sex, $F(1,196)=45.55$, $p<.0001$, and institution, $F(1,196)=29.29$, $p<.0009$, indicating that males performed better than females and VPI undergraduates performed better than Air Force cadets. The reliable interaction of sex and institution, $F(1,196)=31.44$, $p<.0006$, indicates that Air Force Academy females performed significantly poorer than all other students tested (see Figure 9). The poor showing, on the average, for the female cadets seems to be the result of unusually poor performance by a few students. In fact, the variability among female cadets was twice that of the other student groups.

The SAS stepwise linear regression procedure was used to determine prediction equations for ATC booklet scores. Table 3 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 are 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.

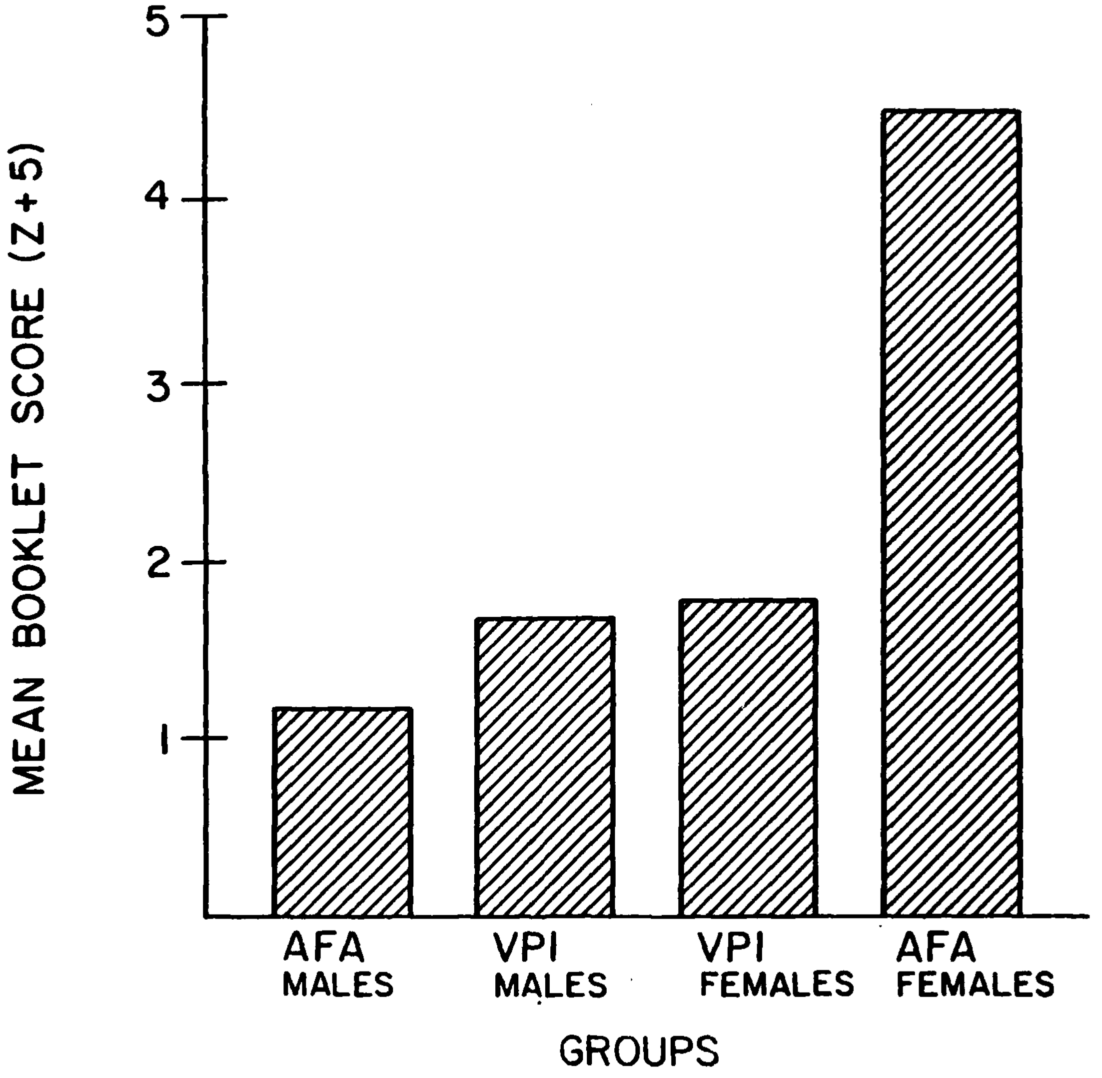


Figure 9. Mean booklet score, including all eight manuevers, on the ATC desk-top trainer.

TABLE 3

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 = Identical Pictures Test
MM = Map Memory Test
PR = Pursuit Rotor
PTD1 = PTD Test 1 - Vector error
PTD2V = PTD Test 2 - Vector error, Two-dimensional tracking
PTD2Z = PTD Test 2 - Error, One-dimensional tracking

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. In addition, our previous success with the regression approach involved an entirely different dependent variable based on training time not transfer task performance.

Two findings from this research are important for pilot selection. First, these data support the contentions of McGrevy and Valentine (1974) that only the second test on the PTD is consistently a reliable predictor of pilot performance. Second, the failure to reveal any common predictors for the pilot performance of male and female cadets suggests that some caution is appropriate when using prediction equations developed with Air Force males to predict the flight performance of female cadets.

PUBLICATIONS

During the contract year two theses were completed, four papers were presented, and two papers were published. These papers summarize the research related to augmented feedback in adaptive training, the regression approach to individual differences, and the prediction of pilot performance. Citations for these papers and presentations are given below. The Appendix includes a copy of each paper or an abstract.

Theses Completed

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.

Papers Presented

Williges, B. H. Computer augmented motor skills training. Paper presented at the International Conference on Cybernetics and Society, Tokyo-Kyoto, Japan, November, 1978.

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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Becker, R. J., Williges, B. H., Williges, R. C., and Koonce, J. M. Prediction of performance in motor skills training. Paper presented at the 23rd annual meeting of the Human Factors Society, Boston, Massachusetts, October, 1979.

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Williges, B. H., Williges, R. C., and Savage, R. E. Predicting optimal training group assignment. Proceedings of the 23rd annual meeting of the Human Factors Society, Boston, Massachusetts, October 1979, 295-299.

PROFESSIONAL PERSONNEL

The research effort was directed by Dr. Robert C. Williges who is a professor of industrial engineering and operations research and of psychology at Virginia Polytechnic and State University. Dr. Williges was assisted by two research associates, John E. Evans, III and Beverly H. Williges, and by four graduate research assistants, Ricky E. Savage, David O. Cote, Richard J. Becker, and Scott Stacey. Mr. Evans is responsible for all computer support at the Human Factors Laboratory and provided the task simulation and systems programming for the project. Ms. Williges managed the empirical research effort. Messrs. Savage, Cote, and Becker participated in the conduct and analysis of the research. Mr. Stacey provided assistance on some of the statistical analyses. Resumes of Dr. Williges, Mr. Evans, and Ms. Williges follow.

ROBERT C. WILLIGES	Professor of Industrial Engineering Professor of Psychology

EDUCATION

A.B., Psychology, 1964	Wittenberg University
M.A., Psychology, 1966	The Ohio State University
Ph.D., Engineering Psychology, 1968	The Ohio State University

EXPERIENCE

Dr. Williges joined the staff of the Department of Industrial Engineering and Operations Research in 1976. Before becoming a member of the faculty at Virginia Polytechnic Institute and State University, he spent eight years from 1968 to 1976 as a member of the Department of Psychology at the University of Illinois at Urbana-Champaign. In addition to his teaching appointment, he was associated both with the Highway Traffic Safety Center (1968-70) where he conducted research on human factors applications to highway systems and the Aviation Research Laboratory (1970-76) where he conducted research dealing with pilot training and enhancement of aircraft controls and displays. While at The Ohio State University he was employed at the Human Performance Center (1964-68) and conducted simulation research on air traffic control systems and human monitoring of complex, computer-generated displays.

Besides his extensive experience in conducting and managing human factors research, he has taught both graduate and undergraduate courses in statistics, research methodology, industrial psychology, human performance, engineering psychology, and human factors in systems design. His publications in human factors include topics dealing with team training, decision making, simple and complex visual monitoring performance, inspection behavior, and human performance in complex system operation including investigation of rate-field, frequency-separated, predictor, computer-generated, and time-compressed displays, interpretability of TV-displayed cartographic information, applications of response surface methodology, motion cues in simulation, transfer of training, and adaptive training procedures.

AFFILIATIONS AND AWARDS

Human Factors Society (Fellow, 1975): editor, Human Factors (1976), associate editor, Human Factors (1973-75), reviewing editor, Human Factors (1971-73), publications board (1974-75), and president, Sangamon Valley Chapter (1971-72); American Psychological Association (Fellow, Division 21, 1975); secretary-treasurer, Division 21 (1972-76); consulting editor Catalog of Selected Documents in Psychology (1975-76); Psi Chi; and occasional reviewing editor for Journal of Experimental Psychology, American Journal of Psychology, Journal of Applied Psychology, and Behavioral Research Methods and Instrumentation. He is listed in the American Men and Women of Science, Who's Who in the Midwest, and 1978 Outstanding Young Men of America, and was awarded the 1974 Jerome H. Ely Award for the outstanding article published in Human Factors during 1973.

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Eisele, J. E., Williges, R. C., and Roscoe, S. N. The isolation of minimum sets of visual image cues sufficient for spatial orientation during aircraft landing approaches. Savoy, Illinois: University of Illinois Institute of Aviation. Aviation Research Laboratory, Technical Report ARL-76-16/ONR-76-3, November 1976.

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BEVERLY H. WILLIGES

Research Associate
Human Factors Laboratory
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EDUCATION

A.B., Psychology, 1965 (cum laude)	Wittenberg University
M.A., Psychology, 1968	The Ohio State University

EXPERIENCE

Ms. Williges joined the staff of the Human Factors Laboratory as a research associate in 1976. Her primary responsibilities include the development and supervision of research on automated training systems, the design of experiments, statistical analysis, and report preparation. From 1971-1976 she was a research associate at the Aviation Research Laboratory, University of Illinois, where she was involved in basic and applied research to develop adaptive systems for pilot training. Previously, she worked for Battelle Memorial Institute, Columbus Laboratories, where she was responsible for the development of self-instructional training programs to be used in industry, government, and education. She was also involved in the collection, evaluation, and interpretation of large-scale survey data. While at Battelle she attended a short course at the University of Michigan for writers of programmed instruction. Her primary research interests are in the areas of motor learning, computed-augmented instruction, and simulation. Her publications include self-instructional training programs and papers dealing with research on simulation, learner-centered instruction, computer adaptive training, and individual differences in motor learning.

AFFILIATIONS AND AWARDS

Human Factors Society: Executive Council, member (1976-1982); Training Technical Group, steering committee (1975-1978), chairperson (1978-1979); Human Factors: Associate editor (1975); consulting editor (1976-1980); Aviation Research Monographs: Associate editor (1971-1973); Alpha Lambda Delta; Psi Chi; Delta Phi Alpha; Mortar Board; Charles Platt Award in Psychology.

PUBLICATIONS

Journal Articles

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EDUCATION

B.S., Electrical Engineering, 1974 (with distinction)	Virginia Polytechnic Institute and State University
M.S., Computer Science and Applications, 1975	Virginia Polytechnic Institute and State University

EXPERIENCE

Mr. Evans joined the staff of the Human Factors Laboratory as a research associate in 1976. He has since been involved in systems software modifications, corrections, and enhancements, and applications software development including real-time simulation, dynamic computer graphics, data reduction, real-time data acquisition, computer transaction systems design and implementation, program debugging aids and instrumentation, and on-line experiment control using interconnected DEC PDP 11/10 and 11/55 mini-computers. In addition, he has been involved in systems and applications software development in the area of magnetic tape file processing, program debugging aids, and program library maintenance on the IBM 370/158 university computers. His laboratory support responsibilities encompass many aspects of digital computation including software maintenance, software design, development, and documentation, computer facilities planning, hardware/software evaluation and acquisition, hardware failure diagnosis, programmer consultation, interface design for custom laboratory peripherals, and technical writing.

Specific areas in which major software development has been concentrated are eye tracking data analysis, adaptive motor skills training, operator performance measurement in computer transaction systems, DEC/IBM magnetic tape data transfer, device specific graphics, software debugging aids, special purpose device handlers, and automated data acquisition. In his current position, Mr. Evans has participated in several funded research programs in the capacity of a software support engineer. Also, he is responsible for the supervision of work assignments and performance review of one systems analyst.

From 1975-1976 Mr. Evans was a systems analyst in the Technical Computer Systems Development Group at Shell Information Center, Shell Oil Company in Houston, Texas, where he was involved in systems software development, program instrumentation, and systems measurement and performance evaluation for UNIVAC 1100 series multiprocessor computers used in geophysical and scientific applications programming. Through the analysis of the effects of the introduction of artificial job mixes to the existing programming environments, he conducted and reported several system impact and utilization studies of projected UNIVAC system loading. In addition, he was involved in utility and user aid software development for the VM/CMS system operating on an IBM 370/158.

Previously, Mr. Evans worked as a graduate research assistant in the Computer Engineering Laboratory, Department of Electrical Engineering, Virginia Polytechnic Institute and State University, where he developed a software system (loaders. utilities, device handlers, cross-assembler, cross-compiler, object time support library, instruction tracer, and interactive debugger) for the GE/PAC 30-2E minicomputer (Interdata 5 equivalent). He also developed an artificially intelligent 3-D 4 x 4 x 4 tic-tac-toe re-entrant game player (95% win rate) for the GE/PAC 30-2E. In addition, he developed an extensive Fortran callable subprogram library providing many processing extensions to ANSI Fortran IV on the IBM 360 operating under OS. Additional programming included several utilities and Fortran callable subprogram packages under OS and a large amount of user-aid software under TSO in support of the laboratory.

During his graduate study, Mr. Evans served on the Computer Resources Committee in the Department of Computer Science. As an undergraduate, he was hired as a student programmer on the Naval Weapons Laboratory Logic Simulator Program CDC to IBM conversion project. He also participated in the Cooperative Education program as a technical assistant electrical engineer with Virginia Electric and Power Company where he was involved in the processing of electric service requests, power distribution planning, protection, and design, power transmission planning and protection, substation design, and automation of calculations for power system protection. He holds an Engineer in Training certificate in the state of Virginia and is currently working on a Ph.D. in Computer Science and Applications. His primary research interests are artificial intelligence, compiling techniques, operating systems, and software transportability.

With a programming career total in excess of 85,000 lines, Mr. Evans has extensive experience with IBM 360/370 under OS, MVS, and VM/CMS, UNIVAC 1108/1110 under EXEC 8, and DEC PDP 11 under RT-11. Programming languages in which he is proficient are Fortran IV/V (most compiler dialects), PL/1, and Assembly (IBM 360/370, UNIVAC 1108/1110, DEC PDP 11, Interdata 5). In addition, he is, to at least a reading understanding, familiar with a large number of other commonly encountered programming languages, job control languages, operator command languages, interactive operating system user languages, etc. Recent job independent projects have included a more powerful and intelligent 3-D 4 x 4 x 4 tic-tac-toe game player on IBM VM/CMS, a support package and conversion rules for translating most CDC Fortran programs to the IBM 360/370 computer in a line-by-line context independent manner, and an interactive line extraction program for use with grey level imagery on the HP 2100A minicomputer.

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Appendix A

A Multiple-Regression Information-Processing Approach for Assigning Individuals to a Training Strategy

A MULTIPLE-REGRESSION INFORMATION-PROCESSING APPROACH FOR ASSIGNING INDIVIDUALS TO A TRAINING STRATEGY

by

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R. E. S.

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INTRODUCTION

When developing a training program, a trainer needs to maximize training efficiency because of such constraints as budget, training time, and need for highly skilled trainees. However, when developing a training program for motor skills, he has no definitive theory or model to serve as a guideline. Therefore, the trainer must choose between two competing approaches: (1) selecting an optimal training model designed for the average trainee, or (2) selecting an optimal training model designed for the individual.

If the choice is the former, the trainer will encounter a fundamental difficulty: this optimal training model will not meet the needs of the individual. Some students will perform well using this particular training model, but others will have difficulty even though they may be good students. The same problem can result even when the training model allows some flexibility or individual adjustments for various skill levels of the student (e.g., adaptive training, Kelley, 1969) since any adjustments will have to be based on the same logic system for all individuals. Generally, this flexibility is not broad enough because individual factors such as learning style, information-processing capabilities, etc., are not taken into consideration. The basic problem with this approach is that the training model is not necessarily matched to the individual characteristics of the student.

The alternative approach is to select a training model that matches certain characteristics of the student to that model. Glaser (1970) stated that in order to maximize training effectiveness for the individual, the goal of training research should be to determine interactions between individual measurements and training strategies. Recent work on cognitive tasks by Pask (1976) supports this approach. Pask found that when the student's preferred learning style and teaching strategy are mismatched, comprehension and retention are severely disrupted.

The research to be reported in this thesis follows the suggestion of Glaser (1970) in trying to match a particular training strategy to individual characteristics. The initial task in proceeding with such research was to discover which individual characteristics relate significantly to a particular training model and to establish a method for selecting a training strategy for the individual based on these characteristics.

Components and Models of Motor Learning

In determining individual characteristics which may relate to a particular training strategy, the trainer has two strategies to consider: the components of motor learning or a theory (or model) of motor learning. The components of motor learning could consist of motor abilities or nonmotor factors which relate to motor skill learning. By measuring these components, the trainer can discover relationships between individual characteristics and various training strategies.

Fleishman and his colleagues (1954, 1958, 1964, 1972) have probably studied the components of motor learning more than any other researchers. The emphasis of their research was on motor abilities using correlational and factor-analytic approaches. From administering some 200 psychomotor tests to thousands of subjects, Fleishman and his associates can account for performance on the tasks in terms of a small number of motor abilities (such as coordination, reaction time, dexterity, etc.) and physical-proficiency abilities (such as static and dynamic strength, stamina, extent flexibility, etc.).

In the area of nonmotor factors and their influence upon motor skills, the research is rather limited. However, some aspects of personality (e.g., Ismail, Kane, and Kirkendall, 1969, extroversion-introversion and stability-neuroticism), stress (e.g., Carron, 1968), and motivation (e.g., Rushall and Pettinger, 1969) have been related to motor skill learning.

A second procedure for determining relationships between individual characteristics and a particular training strategy consists of measuring certain processes or mechanisms of a theory (or model) of motor learning. Some examples consist of Adams's (1968, 1971) closed-loop theory, Whiting's (1969, 1972) systems model of skilled performance, or the information-processing models of Welford (1968), Singer (1975), and Marteniuk (1976).

Several of these components of motor learning (e.g., Fleishman, 1972) could be used to determine relationships with various training strategies. Much of the emphasis of information processing in motor skills, particularly by Welford (1968) and Marteniuk (1976), is that limitations in any of these mechanisms and their various components can limit performance. Although they rarely discuss individual differences specifically, the implications are obvious. If any of these perceptual or cognitive processes involved in information processing can be measured to determine differences in capacities, then individual differences can be studied in how they relate to various training strategies.

Methods, Procedures, and Decision Rules

Having found measurable factors which relate to a particular training strategy, the trainer needs to determine a method or procedure which will provide a decision rule. This decision rule would select a training strategy based on the measures taken from the individual. The development of a decision rule usually involves some type of prediction or heuristic model. This methodological problem will now be considered.

Although there is no definite solution to this problem, several alternative procedures and methods exist. For example, Fleishman (1972) uses primarily correlational or factor-analytic techniques to determine significant components of motor learning; however, both of these procedures offer little in the way of a decision rule. The trainer could use these procedures to determine relationships with a particular training strategy, but he would be forced to develop a heuristic method to serve as a decision rule.

The technique of discriminant analysis offers the basis for a decision rule. This statistical procedure will find not only significant factors that are related to a training strategy, but also classify an individual into one of several categories or training strategies. For purposes of designing a training program based on individual differences, discriminant analysis has definite possibilities. The basic problem with discriminant analysis is the lack of performance information within each training strategy. Discriminant analysis will find individual characteristics that relate to a particular training strategy, but not to performance within that training strategy. Therefore, the lack of performance information can restrict the use of discriminant analysis as a decision rule.

Cronbach (1975) and Cronbach and Snow (1977) propose a procedure which they call "Aptitude-Treatment-Interaction" (ATI). These researchers of individual differences firmly suggest the need to match characteristics of the individual with the instructional strategy. Cronbach suggests the use of regression analysis to determine ATI. By testing the significance of the beta weights of some aptitude on two (or more) treatments, the existence of an ATI can be determined. An ATI effect would indicate that different aptitude scores would result in differential performance in the two treatments (or training strategies). Cronbach further suggests using higher order interactions (i.e., more than one aptitude) to determine a number of factors that significantly relate to various instructional strategies. A specific decision rule is not suggested by Cronbach; however, ATI does provide an effective method for determining relationships between individual characteristics and training strategies. By using the ATI approach, the trainer is again faced with developing a heuristic decision rule.

Conway and Norman (1974) have recently suggested a rather comprehensive and complex procedure which may serve as a decision rule. They propose a self-organizing training system capable of identifying different learning styles. This system is based on a performance profile and a personal history of the individual. Some of the suggested parameters for determining individual differences include previous experience, personality characteristics, cognitive components, psychomotor ability, and the individual's social and educational background. Vreuls, Woolridge, Conway, Johnson, Freshour, and Norman (1977) have applied some of these concepts in the development of a higher-order, partially self-organizing adaptive flight training system. However, this project, still in the initial stages, needs further research to determine its applicability.

Recently, another method was outlined by Savage, Williges, and Williges (1978) in selecting a training strategy, based on individual measures, to train students on a two-dimensional pursuit tracking task. These authors propose a three-phase procedure leading to the development of a decision rule. The first phase consists of developing multiple-regression equations to predict time to train performance in two different training models. The second phase involves the double cross-validation of these regression equations with a second sample of subjects. The final phase is the actual use of the predicton equations in selecting a training strategy for the individual. This last phase would involve matching, mismatching, and randomly assigning subjects to a training condition. The uniqueness of this approach is that individuals are not being classified into one category or another (or one training strategy as opposed to another). Rather, an individual's performance is assessed by obtaining predicted time to train scores in the various training conditions from the regression equations. By using this information, a trainer can assign an individual to a training strategy which results in a savings of training time.

Results of the First Phase

Savage, *et al*. (1978) reported the results of the first phase. The research to be reported in this thesis is an extension of these results; therefore, the first phase data will be discussed in some detail.

These regression equations were based primarily on information-processing variables from Marteniuk's (1976) model. In general, three highly reliable regression equations predicting time to exit (i.e., time to train) were found for each training condition. Table 1 presents the regression equations along with the level of significance (p-value), the multiple R^2 (percent of accounted for variance), the estimate of shrinkage, R_s^2 (Kerlinger and Pedhazur, 1973), and the number of subjects in each equation, n. The predictor variables are in standard score format.

The two regression equations labeled "overall" used all of the subjects in each training condition. Seven predictor variables, listed at the bottom of Table 1, were used. As can be seen, the subject's sex was an important variable only in adaptive training. The next two equations were developed using only the male or female subjects within their respective training condition. With the exception of the fixed training female subjects, these equations, based on the sex of the subject, account for a larger proportion of variance than the overall equations. Furthermore, different sets of predictor variables, not just different weightings, are used in the regression equations based on the sex of the subject. By developing separate regression equations for each sex, Savage, *et al*. (1978) felt that more variance could be

TABLE 1

Regression Equations for Training Time-to-Exit by Training Condition

---

Adaptive/Overall ($n = 31$)

$TE = 1446.13 + 410.08\ EF + 263.93\ SE - 253.19\ MM$

$R^2 = 0.721$

$R_s^2 = 0.690$

$p = 0.0001$

Adaptive/Male ($n = 18$)

$TE = 1069.50 + 509.86\ EF - 325.06\ MM$

$R^2 = 0.750$

$R_s^2 = 0.717$

$p = 0.0001$

Adaptive/Female ($n = 13$)

$TE = 1967.61 - 492.83\ MM + 391.02\ IP - 358.42\ CC + 196.43\ PR$

$R^2 = 0.871$

$R_s^2 = 0.806$

$p = 0.0001$

Fixed/Overall ($n = 28$)

$TE = 1160.73 + 509.20\ EF + 317.78\ IP$

$R^2 = 0.639$

$R_s^2 = 0.610$

$p = 0.0001$

TABLE 1--*Continued*

Fixed/Male ($n = 16$)

$TE = 867.84 + 412.35\ IP + 333.12\ EF$

$R^2 = 0.803$

$R_s^2 = 0.758$

$p = 0.0001$

Fixed/Female ($n = 12$)

$TE = 1551.25 + 411.87\ EF$

$R^2 = 0.431$

$R_s^2 = 0.374$

$p = 0.0205$

TE = Training Time-to-Exit, seconds

PR = Pursuit Rotor (continuous motor skill), time on target

EF = Embedded Figures Test (field independence), time to locate figure

MM = Map Memory Test (visual memory), number correct minus number incorrect

IP = Identical Picutres Test (perceptual speed), number correct minus number incorrect

CC = Cube Comparison Test (spatial orientation), number correct minus number incorrect

MT = Maze Tracing Test (spatial scanning), number correct minus number incorrect

SE = Sex

accounted for because of performance differences found in the pursuit tracking task. The results in Table 1 generally support this notion.

Williges, Williges, and Savage (1978) report data collected on regression equations which attempt to predict mean root-mean-square (RMS) error during a seven-minute transfer task. This task involved the same apparatus used by Savage, *et al.* (1978). The researchers used the same format--male, female, overall--with these equations as they had used in the previous study. These regression equations are presented in Table 2.

In general, these regression equations do not account for as much variance as did the regression equations predicting time to exit performance in the Savage, *et al.* (1978) study. The equations generated for the female subjects were the exceptions in that these equations were generally highly reliable and accounted for a large proportion of variance. Williges, *et al.* (1978) stated that this finding may indicate that task-specific factors dominate for male subjects, whereas general ability factors are characteristic for female subjects in the transfer task. Since these predictor equations use information-processing variables, it may account for the high predictability for female subjects as opposed to male subjects. Therefore, it appears that male subjects may be at a different stage of training in the transfer task and that task-specific variables are evident, whereas female subjects are not at this stage of training in that general abilities are still characteristic.

Williges, *et al.* (1978) attempted to predict performance in the transfer task because a decision rule based on a savings of training

TABLE 2

Regression Equations Predicting Mean RMS Vector Error by Training Condition

---

Adaptive/Overall ($n = 31$)

$RMS = 0.1074 + 0.0162\,EF + 0.0127\,PR - 0.0127\,MT - 0.0109\,MM + 0.0090\,SE$

$R^2 = 0.691$

$R_s^2 = 0.629$

$p = 0.0001$

Adaptive/Male ($n = 18$)

$RMS = 0.0985 + 0.0186\,EF + 0.0093\,IP$

$R^2 = 0.545$

$R_s^2 = 0.484$

$p = 0.0027$

Adaptive/Female ($n = 13$)

$RMS = 0.1197 - 0.0352\,MM - 0.0187\,MT + 0.0175\,PR$

$R^2 = 0.906$

$R_s^2 = 0.875$

$p = 0.0009$

Fixed/Overall ($n = 28$)

$RMS = 0.1090 - 0.0064\,SE + 0.0064\,EF$

$R^2 = 0.452$

$R_s^2 = 0.408$

$p = 0.0005$

TABLE 2--*Continued*

Fixed/Male ($n = 16$)

No reliable equation found

Fixed/Female ($n = 12$)

$RMS = 0.1189 - 0.0076\ IP - 0.0071\ PR + 0.0065\ MT - 0.0044\ MM$

$R^2 = 0.807$

$R_s^2 = 0.697$

$p = 0.0121$

RMS = Root-Mean-Square vector error

PR = Pursuit Rotor (continues motor skill), time on target

EF = Embedded Figures Test (field independence), time to find figure

MM = Map Memory Test (visual memory), number correct minus number incorrect

IP = Identical Pictures Test (perceptual speed), number correct minus number incorrect

CC = Cube Comparison Test (spatial orientation), number correct minus number incorrect

MT = Maze Tracing Test (spatial scanning), number correct minus number incorrect

SE = Sex

time may not be the most desirable or efficient method. How well an individual performs in a transfer task could be the basis for a decision rule. This basis for a decision rule is often of more importance to a trainer than a savings of training time.

Summary

The Savage, *et al.* (1976) and Williges, *et al.* (1968) studies resulted in three principal conclusions. First, information-processing variables, used as predictors, are significant in predicting pursuit tracking performance. Information-processing variables are proposed in several human performance models, but they have not received thorough investigation to determine their importance in motor skill learning. These two studies suggest their validity as topics for research. Second, regression equations, as opposed to other methods, were successfully used to predict pursuit tracking performance and to determine significant predictors of pursuit tracking performance. Again, research has been lacking on the viable use of regression analysis to study individual differences in motor skill learning; these studies point to a successful procedure which can be utilized. Finally, a three-phase methodological approach for determining decision rules was introduced. Therefore, the purpose of the current research is to carry out the second and third phases of this approach. Study I determines the validity of these regression equations presented by Savage, *et al.* (1978) and Williges, *et al.* (1978) using a double cross-validation procedure. Study II experimentally tests the usefulness of these regression equations as a decision rule for assigning individuals to a training strategy.

STUDY I

Introduction

This study began by testing the validity of the regression equations presented by Savage, *et al.* (1978) as a basis for a decision rule. The cross-validation was performed by obtaining a second sample of subjects and correlating the predicted scores from the equations with the actual scores. A double cross-validation procedure was conducted by generating new regression equations from the second sample. The new equations were then used to predict back to the original sample of Savage, *et al.* (1978). The validity of these equations was determined by correlating the predicted scores from the new equations with the actual scores from the original sample. If the correlations appear to be similar (indicating that the regression equations are good predictors of time to exit) and the predictor variables are relatively consistent between the original and new equations, then the two samples could be pooled to produce more stable regression equations (Kerlinger and Pedhazur, 1973). These validation procedures were used both for the regression equations predicting training performance (Savage, *et al.*, 1978) and the regression equations predicting transfer performance (Williges, *et al.*, 1978).

Method

Subjects. Ten male and ten female subjects were randomly assigned to each training condition (adaptive or fixed) for a total of 40 subjects. All subjects were volunteers and were paid for their participation in the experiment. In addition, all subjects were nonpilots, right-handed, and naive about the experiment.

Tests. The same pretest battery used by Savage, *et al*. (1978) and Williges, *et al*. (1978) was given to each subject. Table 3 summarizes the six pretests and their respective reliability correlations.

The first test consisted of six 30-second trials on a Lafayette Instrument Company pursuit rotor. The turntable was 25 cm in diameter and the target was approximately 2 cm in diameter. The pursuit rotor measures general pursuit tracking ability. A previously conducted pilot study found performance on the pursuit rotor correlating -0.76 with adaptive training and -0.71 with fixed training ($n = 10$, all males).

The second test was the Embedded Figures Test (Witkin, Oltman, Raskin, and Karp, 1971). The Embedded Figures Test (EFT) measures the perceptual ability of field independence and field dependence. More specifically, the EFT assesses the ability to break up an organized visual field in order to keep a part of it separate from that field. The better the performance on the EFT, the more field independent one is. Field independence appears to be important in motor skill learning in that it correlates with driving behavior (Goodenough, 1976), piloting (Long, 1972), and tracking (Benfari and Vitale, 1965). Field independence also correlates with arousal level (Oltman, 1964), which Marteniuk (1976) states is necessary for selective attention. Furthermore,

TABLE 3

Tests Used as Predictor Variables

Test:	*Reliability*
Embedded Figures Test (perceptual style of field independence)	0.80
Map Memory (visual memory)	0.77
Identical Pictures (perceptual speed)	0.84
Maze Tracing (spatial scanning)	0.90
Cube Comparison (spatial orientation)	0.77
Pursuit Rotor (continuous motor skill-tracking)	**
I/E Scale (introversion-extroversion)*	0.72
TV Handball (continuous motor skill-tracking)	**

*The I/E Scale and the TV Handball tests were not used in the validation study or in the Savage, *et al.* (1978) study.

**The reliability coefficient is not known.

Cratty (1967) points out that an analytical perceptual style such as field independence is important for early stages of motor skill learning. Considerable interest in the relationship between field independence and motor skills is evident. Much of this interest is based on the fact that field independence has correlated with personality factors such as creativity, social orientation, individuality, and impulsivity and with cognitive factors such as memory and problem-solving behavior. Therefore, performance on the EFT seems to be an important factor in motor skill learning.

The next four tests were paper-and-pencil tests from the Ekstrom, French, Harman, and Dermen (1976) battery. The Map Memory Test is a test of visual memory. It assesses the ability to remember the configuration, location, and orientation of figural material. There is evidence that the coding of motor information in memory is visual and spatial in nature. Marteniuk (1976) states that memory is necessary in continuous motor tasks such as tracking. Furthermore, Marteniuk points out that memory is a factor in the various mechanisms involved in motor performance such as the perceptual mechanism (the detection of and attention to information input), the decision mechanism (the process of how to respond to the information input), and the effector mechanism (the organization of a response). Keele (1973), Laabs (1973), Marteniuk and Roy (1972), and Posner (1967) report that it appears to be a large number of individual differences in memory capacity, particularly the coding of information. Finally, Adams and Dijkstra (1966), Bilodeau, Sulzer, and Levy (1962), and Posner (1967) postulate that an "image" may be the form that movement-related information takes in short-term memory. Therefore, the Map Memory Test was chosen to tap short-term visual memory capacity by measuring how well the individual can remember visual information.

The Identical Pictures Test is a test of perceptual speed. This test assesses speed in comparing figures or symbols, or carrying out other very simple tasks involving visual perception such as how rapidly an individual can process perceptual information. Fleishman and Hempel (1954, 1956) found this factor important in motor skill learning. Marteniuk (1976) discussed the necessity of an individual to detect rapidly and to filter out perceptually irrelevant information in motor learning. Other aspects of perceptual speed involve selective attention, scanning and searching, and pattern recognition. Thus, this test assesses an individual's ability to handle and reduce perceptual information.

The Cube Comparisons Test measures spatial orientation. It assesses the ability to perceive spatial patterns or to maintain orientation with respect to objects in space. This test measures how well an individual can maintain a clear spatial perspective of objects in the environment. Cratty (1967) and Marteniuk (1976) pointed out that the coding of motor information appears to be spatial as well as visual. Fleishman and Rich (1963) have demonstrated that subjects who were best in spatial sensitivity performed better, early in learning, than those who were worst in spatial sensitivity. This study again demonstrates that spatial-visual information is important in motor learning.

The Maze Tracking Test is a test of spatial scanning. This test assesses the speed in exploring visually a wide or complicated spatial field and measures how well an individual can visually scan a field quickly for the correct path. This scanning behavior is often called visual pursuit. The logic for this test is basically the same as for spatial orientation. The specific task, maze tracing, is similar to a pursuit tracking task which could indicate a good predictor of pursuit tracking performance.

Training conditions. A two-dimensional pursuit tracking task was used in the training task involving two possible training approaches: fixed difficulty and adaptive. The fixed difficulty training condition uses the traditional approach to motor skill training in which the trainees are presented the criterion task initially and their error decreases as training progresses. This approach does not allow for individual differences which often results in the task being too difficult or too easy for the trainee.

The adaptive training condition involves an adaptive logic which manipulates task difficulty in a closed-loop system (Kelley, 1969). In a closed-loop system, feedback from the output of the former system is present and can be used to modify subsequent outputs. Therefore, student performance is monitored and compared to a standard. The system adjusts the difficulty of the training task so that the performance of the student is relatively stable throughout training. The result is that the adaptive training condition adjusts to individual skills through the feedback loop. The adaptive logic in this task used a total of 1,851 task difficulty steps requiring a minimum time of 111.1 seconds to reach the exit criterion level of difficulty.

Equipment. The training and transfer tasks were generated using a laboratory-developed software package run on a Digital Equipment Corporation PDP 11/55 digital computer which is linked to a Tektronix 4014-1 computer display terminal and a Measurement System Model 435 two-axis pressure control stick. The software responsible for generating the tracking task was developed around two independent real-time cycles: a 60-Hz cycle to refresh the display and a 60-ms cycle to calculate and update the task. (See Appendix I for a more detailed description of the equipment and the software, and see Appendix II for the software source listing.)

Procedure. Each subject completed the battery of six pretests to acquire scores for the predictor variables. First, the subject tracked on the pursuit rotor to six 30-second trials with a 10-second rest period between each trial. Each trial began with the stylus resting on the target. The subject was to keep the stylus on the target while the turntable rotated in a clockwise motion at 6.005 radians/second. The mean time on target across the six trials was the score for this test.

Next, the EFT was administered and was contained on 7.6 cm by 12.7 cm cards. Each subject had one practice trial which consisted of viewing a complex figure for 15 seconds after which a simple figure was viewed for 10 seconds. Finally, the subject was shown the complex figure again and was instructed to locate the embedded simple figure.

The sum of the times required to find the simple figure for the 12 trials was the score for the EFT.

The next four tests were paper-and-pencil tests enclosed in three to six page booklets. The first page of each test contained instructions and practice items, and each test had two parts. The score for each test was the average of the two parts. Each part of each test was scored by subtracting the number of incorrect items from the number of correct items. The Cube Comparison Test contained 21 pairs of cubes and a three minute time limit for each part. The subject's task was to indicate which items present drawings that can be of the same cube and which items present drawings of different cubes. For the Map Memory Test, each part consisted of a study page and a test page with three minutes for studying and three minutes for testing. Both parts contained 12 maps. The task was to identify maps which were presented on the previous study page. Each part of the Identical Pictures Test consisted of 48 items with one and one-half minutes allowed for each part. The subject's task was to identify which one of five pictures was identical to a standard figure. Finally, the Maze Tracing Test contained 24 mazes and a three minute time limit for each part. The task was to find and mark an open path through the series of mazes.

Following the completion of the six pretests, each subject learned a pursuit tracking training task illustrated in Figure 1. The training task involved two independent, random, band-limited functions which determined the X-Y coordinates of the forcing function symbol ("X") on the display. The boundaries of the symbol movement are determined by the band-limited function. The control output ("O") was generated from

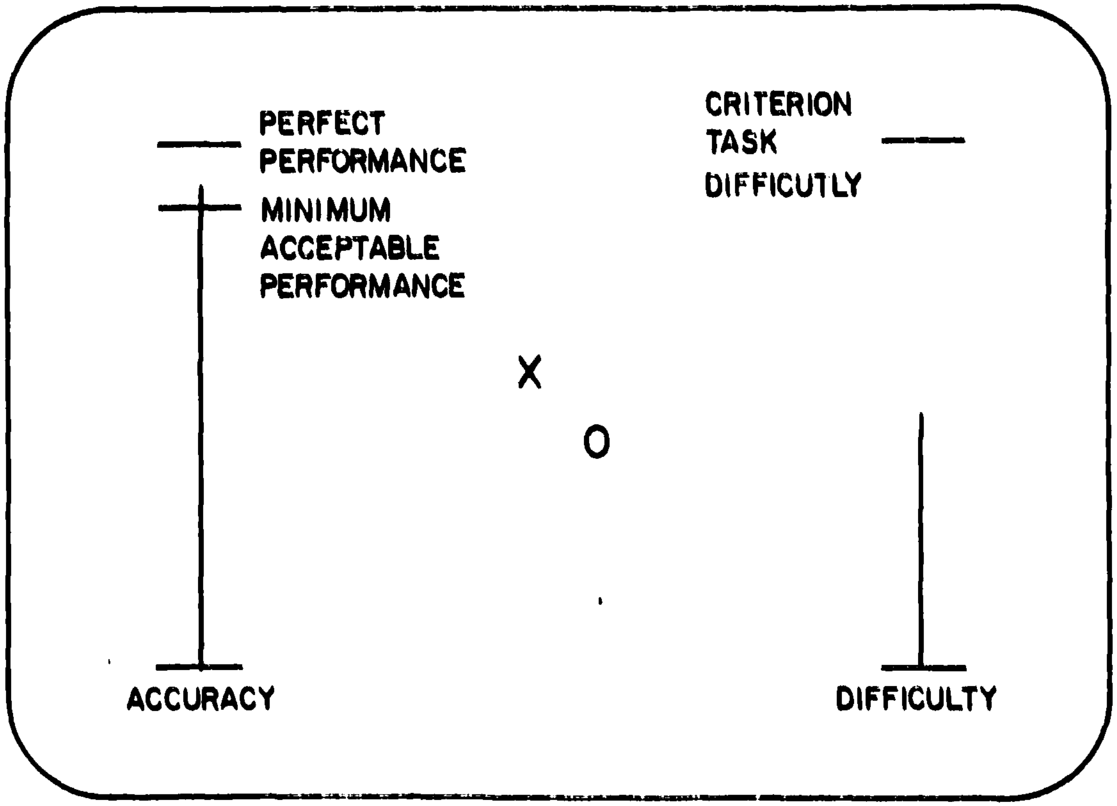

Figure 1. The pursuit tracking task

inputs from the isometric controller. The symbol size was a 0.64 × 0.48 cm rectangle on the Tektronix screen. The tracking area on the screen was 18 cm × 18 cm. Feedback bars appeared outside this area. In Figure 1, the left feedback bar displays tracking accuracy with the tolerance limits defined by the horizontal lines at the top of the bar. The right feedback bar displays the level of difficulty of the task with the top of the bar being the exit criterion. In order to exit from the task, subjects had to maintain the exit criterion level of difficulty and an acceptable tracking accuracy for a period of 20 seconds. The viewing distance from the screen was 1 m. A forehead rest was used to maintain a constant viewing distance.

The control system dynamics were neither pure rate nor pure acceleration. With pure acceleration dynamics, the task would have involved an unreasonable amount of time to learn the task, while with pure rate dynamics, the task would have been too simple for most subjects. The order of the control system was 1 + α, where α is the proportion of acceleration control. The positions of the "O" were calculated using both pure rate and pure acceleration dynamics for each control stick output. The following transfer function describes the system dynamics in each axis:

$$\Theta_{OX}(S) = (1 - \alpha)K_1 \frac{\Theta_{iX}}{S} + \alpha K_1 K_2 \frac{\Theta_{iX}}{S^2} \qquad (1)$$

where

$\Theta_{OX}(S)$ = the Laplace transform of the scalor 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, and

S = the Laplace transform independent variable.

In the present study, α was equal to 0.80. The constants K_1 and K_2 were derived as a function of the maximum allowable speed of the "O" (50.8 cm/s) and the tracking area on the display (see Appendix I). In equation (1), K_1 was equal to 1.8139 cm/s/N and $K_2 = 1.4285713\ s^{-1}$.

Task difficulty was manipulated in terms of the movement of the forcing function symbol ("X") and was generated by the minicomputer by simulating a computer-operated control stick. The simulated control stick output would be Θ_{iX} in equation (1). The constants K_1 and K_2 are again derived as a function of the maximum allowable speed of the "X" (20.3 cm/s), the minimum speed of the "X" (0.025 cm/s), and the tracking area on the display (see Appendix I). The constant K_1 was 0.7246 cm/s/N and K_2 was equal to 0.57[illegible]6 s^{-1}. A random number generator internal to the minicomputer simulated the input of the forcing function.

The adaptive logic used 1851 task difficulty steps which required 111.1 s to reach exit criterion. The criterion level of task difficulty was the maximum movement speed of the forcing function symbol ("X"): 20.3 cm/s. The tolerance limit was 10% of the screen diagonal (2.5 cm). Absolute tracking error was computed every 60 ms.

A maximum of 15 three-minute trials alternating with one-minute rest periods were given to avoid possible fatigue effects. There was a [illegible]-minute rest between the training and transfer tasks.

The transfer task was similar to the training task except that no performance information (feedback bars) was provided. The transfer task lasted six minutes during which three levels of difficulty in terms of the maximum speed of the forcing function changed each minute. The three levels of difficulty consisted of the exit criterion (20.3 cm/s, level of difficulty 2), more difficult than the exit criterion (30.5 cm/s, level of difficulty 3), and less difficulty than the exit criterion (10.2 cm/s, level of difficulty 1). The order to task difficulties presented was the same for each subject: levels of difficulty 2, 1, 3, 1, 2, 3.

Results and Discussion

Training data. A double cross-validation procedure was employed where the original equations were used to predict time to exit performance for the new sample (R_{12}^2), and new regression equations were generated from the new sample and used to predict time to exit performance for the first sample (R_{21}^2). For both samples, correlations were calculated between the predicted and the actual scores (R_{11}^2 and R_{22}^2). These correlations are presented in Table 4.

It was expected that a reduction or shrinkage would occur in the cross-validation correlations when compared to the original correlations due to the new samples of subjects and different testing times. When the regression equations from the first sample were used to predict time to exit performance for the second sample, the cross-validated squared correlations (R_{12}^2) were similar to the estimates of shrinkage (R_1^2). However, the regression equations for the adaptive female and

TABLE 4

Coefficients of Multiple Determination from Cross-Validation

	Overall	Male	Female
Adaptive Training:			
$R^2_{\hat{1}1}$	0.721	0.750	0.817
$R^2_{s_1}$	0.690	0.717	0.756
$R^2_{\hat{1}2}$	0.832	0.619	0.306
$R^2_{\hat{2}2}$	0.859	0.841	0.827
$R^2_{s_2}$	0.833	0.796	0.741
$R^2_{\hat{2}1}$	0.699	0.578	0.511
Fixed Difficulty Training:			
$R^2_{\hat{1}1}$	0.639	0.803	0.431
$R^2_{s_1}$	0.610	0.758	0.374
$R^2_{\hat{1}2}$	0.444	0.178	0.482
$R^2_{\hat{2}2}$	0.611	0.474	0.905
$R^2_{s_2}$	0.538	0.324	0.856
$R^2_{\hat{2}1}$	0.472	0.333	0.003

NOTE: $R^2_{\hat{1}1}$ = variance accounted for of regression equation, original sample; $R^2_{s_1}$ = estimate of shrinkage, original sample; $R^2_{\hat{1}2}$ = squared correlation of predicted scores with actual scores of new sample; $R^2_{\hat{2}2}$ = variance accounted for of regression equation, new sample; $R^2_{s_2}$ = estimate of shrinkage, new sample; $R^2_{\hat{2}1}$ = squared correlation of predicted scores with actual scores of original sample.

fixed male subjects did not produce correlations similar to the estimate of shrinkage. When the new regression equations generated from the second sample were used to predict time to exit performance for the first sample, the cross-validated squared correlations ($R^2_{\hat{2}1}$) were again similar to the estimates of shrinkage ($R^2_{s_2}$). The exception was the regression equation developed for the fixed female subjects. Although the cross-validated squared correlation for the fixed male subjects was similar to the estimate of shrinkage, the multiple squared correlation ($R^2_{\hat{2}2}$) was relatively low initially.

Several aspects of these data should be noted. First, the multiple squared correlations and the cross-validated squared correlations were consistently high for the overall regression equation. Furthermore, when comparing the regression equations derived from the first sample and the second sample, the predictor variables were consistent. The only exception was the addition of a new predictor variable for the overall fixed training regression equation; however, it was the least weighted variable. The regression equations developed separately for male and female subjects were not consistent in the cross-validation procedure, and the predictor variables had a tendency to change in the regression equation from the second sample when compared with the regression equation from the first sample.

Given these results, the two samples were combined and an overall regression equation was calculated for both training models. These combined overall regression equations are shown in Table 5. Each of these regression equations predicting time to exit performance is reliable at the 0.0001 level of significance. Both regression equations

TABLE 5

Combined Sample Regression Equations for Training Time to Exit

---

Adaptive:

$TE = 1326.85 + 381.82\ EF - 307.48\ MM + 259.52\ SE$

$n = 51$

$R^2 = 0.756$

$R_s^2 = 0.740$

$p \leq 0.0001$

Fixed Difficulty:

$TE = 994.57 + 405.77\ EF + 251.3\ IP - 139.28\ CC$

$n = 48$

$R^2 = 0.632$

$R_s^2 = 0.607$

$p \leq 0.0001$

CC = Cube Comparison Test, number correct minus number incorrect

EF = Embedded Figures Test, time to locate simple figure

IP = Identical Pictures Test, number correct minus number incorrect

MM = Map Memory Test, number correct minus number incorrect

SE = Sex

have the same dominant predictor variable: the Embedded Figures Test. All other predictor variables are different. Sex is a reliable predictor variable only in the regression equation for adapative training. These differences in the regression equations should be sufficient to discriminate time to exit performance between the two training strategies to serve as a decision rule to determine a training strategy for the individual.

Transfer data. Table 6 presents the double cross-validation data for the regression equations predicting mean RMS vector error in the transfer task. These data did not cross-validate in that the cross-validated squared correlations (R^2_{12} and R^2_{21}) fail to compare with the estimates of shrinkage ($R^2_{s_1}$ and $R^2_{s_2}$). There were three statistically significant correlations: the overall regression equation for adaptive training, $r_{21} = 0.370$, $p < 0.05$, and the overall regression equations for fixed training, $r_{12} = 0.546$, $p < 0.01$, and $r_{21} = 0.464$, $p < 0.05$. Because of these statistically significant correlations, the two samples were combined to develop an overall regression equation for each training model. These regression equations appear in Table 7. Both regression equations are reliable at the 0.0001 level of significance. As was found with the regression equations predicting time to exit performance, the Embedded Figures Test is the dominant predictor variable. The only predictor variable not common to both regression equations is the Cube Comparison Test in fixed training.

The predictor variable in the combined overall regression equations presented in Table 7 were all contained in either the regression equation

TABLE 6

Coefficients of Multiple Determination from Cross-Validation

	Overall	Male	Female
Adaptive Training:			
$R^2_{\hat{1}1}$	0.691	0.545	0.906
$R^2_{s_1}$	0.629	0.484	0.875
$R^2_{\hat{1}2}$	0.027	0.036	0.124
$R^2_{\hat{2}2}$	0.474	0.383	0.824
$R^2_{s_2}$	0.412	0.306	0.736
$R^2_{\hat{2}1}$	0.137*	0.046	0.001
Fixed Difficulty Training:			
$R^2_{\hat{1}1}$	0.454	-----	0.807
$R^2_{s_1}$	0.408	-----	0.697
$R^2_{\hat{1}2}$	0.298**	-----	0.191
$R^2_{\hat{2}2}$	0.507	0.642	0.369
$R^2_{s_2}$	0.415	0.597	0.290
$R^2_{\hat{2}1}$	0.215*	0.043	0.109

*$p < 0.05$. **$p < 0.01$.

NOTE: For definition of terms, see Table 4.

TABLE 7

Combined Sample Regression Equations for Predicting Transfer Performance

---

Adaptive Training:

$RMS = 0.1088 + 0.0123\ EF + (-0.0071)\ MM + 0.0062\ SE$

$R^2 = 0.445$

$R_s^2 = 0.410$

$n = 51$

$p = 0.0001$

Fixed Difficulty Training:

$RMS = 0.1078 + 0.0086\ \mathrm{EF} + 0.0068\ \mathrm{SE} + 0.0067\ \mathrm{CC} + (-0.0042)\ \mathrm{MM}$

$R^2 = 0.462$

$R_s^2 = 0.412$

$n = 48$

$p = 0.001$

EF = Embedded Figures Test, time to locate simple figure

MM = Map Memory Test, number correct minus number incorrect

CC = Cube Comparison Test, number correct minus number incorrect

SE = Sex

developed from the first sample or the regression equation developed from the second sample. The two regression equations calculated from the two samples separately were very dissimilar. Therefore, these regression equations predicting mean RMS vector error in the transfer task need to be validated with a second sample of subjects.

STUDY II

Introduction

The purpose of the second study was to test the usefulness of the regression equations as a decision rule; that is, can one optimize the training of an individual by using predicted scores from the regression equations to determine the best training condition for that individual? To determine the usefulness of these equations, subjects were either matched or mismatched, according to their predicted time to exit scores, to a training strategy. If a significant difference exists between the matched and mismatched subjects, with the matched subjects requiring less time to train, then it would appear that the equations are useful for assigning subjects to an optimal training strategy when subjects are mismatched.

A third treatment (aside from matched and mismatched) was a random assignment condition in which subjects were randomly assigned to a training strategy. A significant difference between the matched condition and the random condition, with the matched subjects exhibiting superior performance, would not only demonstrate that subjects are properly matched to their respective training condition, but it would be an indication of the predictive power of the regression equations, in that approximately 50% of the subjects in the random condition would be assumed to be properly matched to a training condition initially.

This experiment also served as a second validation of the existing regression equations predicting training performance and the validation of the regression equations predicting transfer performance. As in Study I, the predicted scores will be correlated with the actual scores.

Method

Experimental design and analysis. Figure 2 gives a pictorial representation of the 2 × 2 × 3 factorial experimental design for the training task. The variables are training (adaptive and fixed), sex (male and female), and assignment (matched, mismatched, and random). All of the variables are between-subject effects and an analysis of variance (ANOVA) was used to analyze the data. The experimental design for the transfer task included the additional within-subject variable of level of difficulty. The Newman-Keuls multiple comparison test was used to analyze all significant effects.

The present experiment served as a second validation of the regression equations predicting both training and transfer performance (see Tables 5 and 7). The validation analysis consisted of correlating the predicted scores with the actual scores. Finally, new regression equations predicting mean RMS vector error in the transfer task were generated using the two additional tests. This analysis used five stepwise procedures from the SAS package (see Barr, Goodnight, Sall, and Helwig, 1976).

Materials and procedure. The equipment, training conditions, and tests and their procedures were the same as in the first study. In addition to the six tests described in Study I, two additional, supplemental tests were administered. The I/E Scale (Rotter, 1954, 1966)

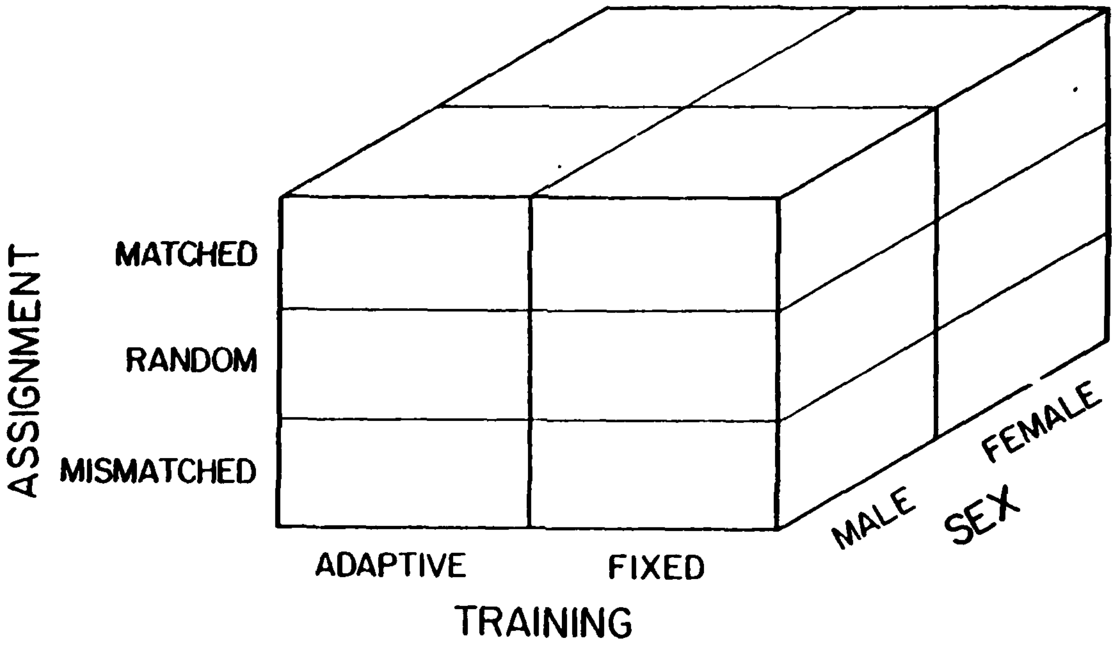

Figure 2. The experimental design

involves subjects answering questions about situations of interest in our society over which they may be perceived to have control or over which they perceive external factors to have control. The answers to these questions consisted of choosing which statement they believed to be more true. Ryckman (1978) found the I/E Scale to correlate with tracking performance on a pursuit rotor.

The second additional test was a TV handball game which consisted of maximizing the time in the game. The task involved hitting a ball with a paddle which the subject controlled in a vertical dimension. The more often the subject hits the ball, the longer he stays in the game. Once the subject missed the ball 15 times, the game ended and the time was recorded. The game was displayed on a 48.3 cm television screen. A pilot study found this motor task to be correlated with mean transfer performance (RMS vector error): $r = -0.642$ for adaptive training and 0.422 for fixed training ($n = 10$, all males).

The addition of the I/E Scale assesses one aspect of the personality domain of the individual which follows the suggestion of Conway and Norman (1974), whereas the addition of the TV handball could be considered as a task-specific factor which follows the suggestion of Williges, *et al.* (1978). These new tests will be used with the other six tests to develop new regression equations for predicting transfer performance in an attempt to account for more variance than the present regression equations presented in Table 7.

Assignment of the subjects. The critical aspect of this experiment involved the assignment of the subjects to a training condition using the predicted time to exit scores of the regression equations presented in Table 5. The first step in the assignment was to randomly assign 20 male and 20 female subjects to the matched, mismatched, or random condition. If the subject were in the random condition, then he/she would be randomly assigned to one of the two training conditions. However, the predicted time to exit scores from the regression equations in Table 5 determined which training condition the subject received in both the matched and mismatched conditions.

Results and Discussion

Training data. The results of the ANOVA on the time to exit scores (measured in seconds) found two significant effects: sex and assignment. The cell means are presented in Table 8 and the ANOVA summary table is presented in Table 9. For the main effect of sex, male subjects required significantly less time to exit than female subjects. The mean time to exit for male subjects was 685.42 s; whereas, for female subjects the mean time to exit was 1306.09 s. The Newman-Keuls test found that for the assignment main effect, the matched subjects required significantly less time to exit than either the random or the mismatched subjects at the 0.01 level. The difference between the random and mismatched subjects was not reliable. The mean time to exit was 599.38 s for the matched subjects, 1122.08 s for the random subjects, and 1265.80 s for the mismatched subjects.

The results strongly support the use of these regression equations as a decision rule which selects a training strategy for the individual. When subjects are matched to a training strategy, a savings of 47% in

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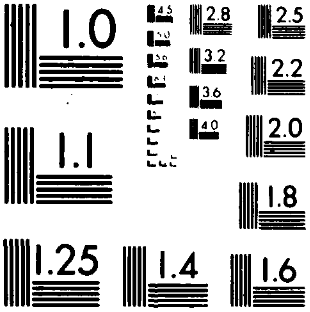

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

TABLE 8

Cell Means for the ANOVA on the Time to Exit Data

	Adaptive Training		Fixed Training		
	Male	Female	Male	Female	Mean
Matched	324.97	834.37	430.70	807.50	599.38
Random	694.96	1633.39	937.59	1222.37	1122.08
Mismatched	1013.00	1814.51	711.28	1524.41	1265.80
Mean	677.64	1427.42	693.19	1184.77	

TABLE 9

ANOVA Source Table for the Time to Exit Data

Source	*df*	*MS*	*F*	*p*
Training (T)	1	386864.852	1.36	≤ 0.2464
Assignment (A)	2	4919876.150	17.27	≤ 0.0001
Sex (S)	1	11557148.496	40.57	≤ 0.0001
T × A	2	287595.476	1.01	≤ 0.3678
T × S	1	500037.867	1.76	≤ 0.1880
A × S	2	332250.314	1.17	≤ 0.3154
T × A × S	2	306203.480	1.07	≤ 0.3449
Subjects/TAS	108	284842.349		

training time can result when compared to subjects who are randomly assigned and a savings of 53% when compared to subjects who are mismatched. Therefore, when the goal of designing a training program is to maximize savings in training time, the trainer would profit by using a similar methodology of matching subjects with a training strategy.

Theoretically, the random condition should have 50% of the subjects matched and 50% mismatched. In this study, the random condition resulted in 22 subjects matched and 18 subjects mismatched. These subjects' data were then placed in the respective assignment conditions which results in two levels of the assignment variable. An unequal *ns* ANOVA was then conducted.

The results again found a significant main effect of assignment. The cell means are presented in Table 10 and the ANOVA source table is presented in Table 11. The mean time to exit was 769.18 s for the matched subjects and 1237.96 s for the mismatched subjects. The assignment by sex interaction was also significant. The Newman-Keuls test found that the mismatched female subjects were significantly different from the matched male subjects, the matched female subjects, and the mismatched male subjects at the 0.01 level. There were no other reliable differences. The mean time to exit for the mismatched female subjects was 1652.91 s; whereas, the mean time to exit was 590.96 s, 793.36 s, and 959.27 s for the matched male subject, the mismatched male subjects, and the matched female subjects, respectively. The results of this interaction are presented in Figure 3.

TABLE 10

Cell Means for the Unequal *n*s ANOVA on the Time to Exit Data

	Adaptive Training		Fixed Training		
	Male	Female	Male	Female	Mean
Matched	520.91	908.27	670.36	988.80	769.18
Mismatched	882.60	1727.99	716.02	1523.23	1237.96

TABLE 11

Unequal *ns* ANOVA Source Table for the Time to Exit Data

Source	*df*	*MS*	*F*	*p*
Training (T)	1	35635.63	0.11	≤ 0.7355
Assignment (A)	1	5574623.12	17.94	≤ 0.0001
Sex (S)	1	10007378.31	32.20	≤ 0.0001
T × A	1	650364.04	2.09	≤ 0.1508
T × S	1	20646.17	0.07	≤ 0.7971
A × S	1	1611813.39	5.19	≤ 0.0247
T × A × S	1	1699.38	0.01	≤ 0.9412
Subjects/TAS	112	310754.18		

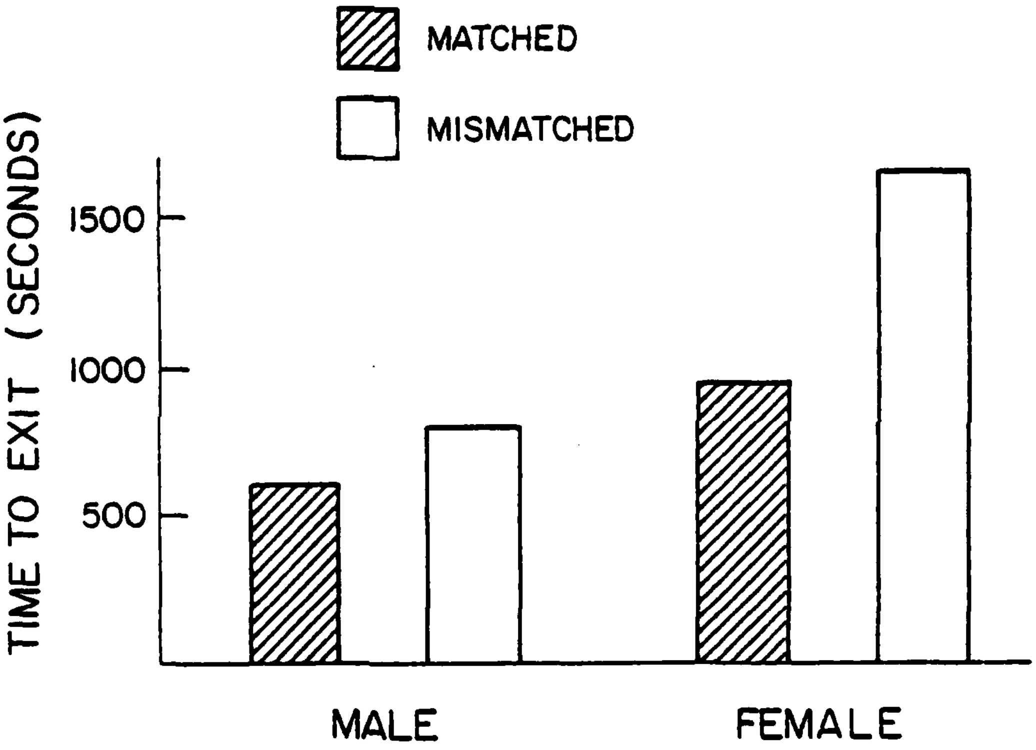

Figure 3. The sex by assignment interaction.

Two significant results were found from the training data. First, male subjects generally required about half the time to learn the task that the female subjects required. Second, when subjects were matched to a training condition, a 47 to 53% savings in training time resulted when compared with the random or mismatched conditions. However, the unequal *ns* ANOVA showed that this result is primarily due to the mismatched female subjects. There was no significant difference between the matched and mismatched male subjects in the assignment by sex interaction.

Transfer data. The results of the ANOVA on the RMS vector error found three main effects and one interaction significant. The cell means are presented in Table 12 and the ANOVA summary table is presented in Table 13. The level of difficulty was found to be highly reliable with the subsequent Newman-Keuls test finding all three levels of difficulty reliably different at the 0.01 level. The RMS vector error was 0.0711, 0.1160, and 0.1486, respectively, for the lowest level of difficulty, the exit criterion of difficulty, and the highest level of difficulty. The effect of sex was also highly reliable with a mean RMS vector error of 0.1020 for male subjects and 0.1218 for female subjects. The sex by level of difficulty interaction was also found to be reliable. The Newman-Keuls test resulted in all possible combinations being reliable at least at the 0.05 level. Generally, male subjects had smaller error than female subjects at each level of difficulty.

The main effect of assignment resulted in a reliable difference. The Newman-Keuls test found that matched and random subjects had a

TABLE 12

Cell Means for the ANOVA on the RMS Vector Error Rate

	Adaptive Training		Fixed Training		
	Male	Female	Male	Female	Mean
Matched	0.0840	0.0937	0.1035	0.1198	0.1003
Random	0.0982	0.1260	0.0949	0.1207	0.1099
Mismatched	0.1088	0.1349	0.1226	0.1359	0.1255
Mean	0.0970	0.1182	0.1070	0.1255	

TABLE 13

ANOVA Source Table for the Transfer Task Data

Source	*df*	*MS*	*F*	*p*
Training (T)	1	0.0066977	2.74	$\leq$ 0.1008
Assignment (A)	2	0.0195094	7.98	$\leq$ 0.0006
Sex (S)	1	0.355057	14.53	$\leq$ 0.0002
T × A	2	0.0055405	2.27	$\leq$ 0.1086
T × S	1	0.0001613	0.07	$\leq$ 0.7977
A × S	2	0.0014335	0.59	$\leq$ 0.5581
T × A × S	2	0.0007099	0.29	$\leq$ 0.7485
Subjects/TAS	108	0.0024444		
Level of Difficulty (L)	2	0.1815312	386.22	$\leq$ 0.0001
T × L	2	0.0003596	0.77	$\leq$ 0.4666
A × L	4	0.0005550	1.82	$\leq$ 0.1262
S × L	2	0.0024918	5.30	$\leq$ 0.0057
T × A × L	4	0.0004767	1.01	$\leq$ 0.4009
T × S × L	2	0.0006420	1.37	$\leq$ 0.2573
A × S × L	4	0.0002715	0.58	$\leq$ 0.6792
T × A × S × L	4	0.0001069	0.23	$\leq$ 0.9228
L × Subjects/TAS	216	0.0004700		

smaller RMS vector error than mismatched subjects ($p \leq 0.01$ and $p \leq 0.05$, respectively), whereas the matched and random subjects were not reliably different. The mean RMS vector error was 0.1003, 0.1100, and 0.1255, respectively, for the matched, random, and mismatched conditions. This result suggests that by matching subjects to a training condition based on time to exit scores, they will have significantly smaller RMS vector error than subjects who are purposely mismatched. The matched subjects, however, will not be better than subjects who are randomly assigned. Therefore, if the goal of a training program is to maximize transfer task performance by matching subjects based on time to exit scores, then these data are not necessarily supportive of this goal because of the lack of a reliable difference between the matched and random subjects.

Given that 22 subjects were matched and 18 were mismatched in the random condition, an unequal *n*s ANOVA was also performed on the transfer task data. The cell means are presented in Table 14 and the ANOVA summary table is presented in Table 15. These results found two reliable effects: training and assignment. Subjects trained adaptively had significantly less RMS vector error than subjects trained in the fixed condition. The mean RMS vector error was 0.1076 and 0.1162 for the adaptive and fixed, respectively. For the effects of assignment, matched subjects had significantly smaller error in transfer than mismatched subjects. The mean RMS vector error was 0.1030 and 0.1215 for matched and mismatched, respectively. These two results suggest that error can be successfully reduced in transfer by training subjects adaptively or by matching subjects to a training condition. An 8% reduction in error was obtained by the adaptive training condition, whereas an 18% reduction

TABLE 14

Cell Means for the Unequal *n*s ANOVA on the RMS Vector Error Data

	Adaptive Training		Fixed Training		
	Male	Female	Male	Female	Mean
Matched	0.0917	0.0957	0.1027	0.1175	0.1030
Mismatched	0.1040	0.1312	0.1112	0.1393	0.1215

TABLE 15

Unequal *ns* ANOVA Summary Table for the Transfer of Task Data

Source	*df*	*MS*	*F*	*p*
Training (T)	1	0.01249	5.05	$\leq$ 0.0266
Sex (S)	1	0.03283	13.27	$\leq$ 0.0004
Assignment (A)	1	0.02973	12.01	$\leq$ 0.0005
T × A	1	0.00165	0.67	$\leq$ 0.4155
T × S	1	0.00072	0.29	$\leq$ 0.5901
A × S	1	0.00718	2.90	$\leq$ 0.0913
T × A × S	1	0.00051	0.21	$\leq$ 0.6495
Subjects/TAS	112	0.00248		
Level of Difficulty (L)	2	0.17528	373.85	$\leq$ 0.0001
T × L	2	0.00050	1.06	$\leq$ 0.3465
A × L	2	0.00125	2.67	$\leq$ 0.0717
S × L	2	0.00248	5.28	$\leq$ 0.0057
T × A × L	2	0.000027	0.06	$\leq$ 0.9447
T × S × L	2	0.000820	1.75	$\leq$ 0.1766
A × S × L	2	0.000260	0.55	$\leq$ 0.5757
T × A × S × L	2	0.000130	0.27	$\leq$ 0.7658
L × Subject/TAS	224	0.000470		

of error was obtained by the matched condition. Therefore, if the goal of the trainer is to maximize transfer performance, then trade-off considerations need to be considered based on these results.

Validation results. This study also provided an opportunity to validate the cobmined overall regression equations previously presented in Tables 5 and 7. As in Study I, the predicted scores were correlated with the actual scores. In considering first the regression equations in Table 5 for predicting time to exit performance in adaptive training, the correlation between the predicted scores and the actual scores was $r = 0.789$, $p = 0.0001$. The R^2 was 0.623, which was somewhat lower than the estimate of shrinkage (R_s^2) is Table 5. The regression equation for the fixed training resulted in an $r = 0.716$, $p = 0.0001$. The R^2 was 0.5131, which again was somewhat lower than the estimate of shrinkage (R_s^2) in Table 5.

Additionally, the regression equations in Table 7 predicting mean RMS vector error in transfer were also validated. The regression equation for fixed training resulted in a near zero correlation and, therefore, showed no signs of being a valid equation. However, the regression equation for adaptive training resulted in a $r = 0.574$, $p = 0.0001$. The R^2 was 0.330, which was lower than the estimate of shrinkage (R_s^2) in Table 7. It should be noted that the variance accounted for by this equation was less than 33%, which is relatively low in comparison to the equations predicting time to exit performance.

Given that the regression equations predicting transfer performance were either not valid or accounted for a small proportion of variance, new equations were calculated using the results of the two additional tests. These equations are presented in Table 16. Both equations are highly reliable, but the equation for fixed training only accounted for a small proportion of variance, 26%. The regression equation for adaptive training accounted for 43% of the variance in the transfer task. The validity of this equation needs to be determined. In general, success in predicting performance in the transfer task is lacking. Fleishman (1972) and Williges, *et al.* (1978) suggest that task-specific variables are evident late in learning (or training) and that general ability factors (e.g., information-processing skills) become less important. If this is the situation in the present transfer task, then task-specific variables are needed to predict performance. The equations in Table 16 show some support for task-specific variables in that both equations contain a measure of tracking performance (the pursuit rotor and the television handball) which could be considered task-specific variables.

TABLE 16

New Regression Equations Predicting Transfer Performance

Adaptive

$RMS = 0.107597 + 0.014449\ EF + (-0.007982)\ PR$

$R^2 = 0.429$

$R_s^2 = 0.409$

$n = 60$

$p = 0.0001$

Fixed

$RMS = 0.116224 + (-0.012541)\ CC + (-0.008249)\ TV$

$R^2 = 0.263$

$R_s^2 = 0.237$

$n = 60$

$p = 0.0002$

EE = Embedded Figures Test, time to find simple figure

PR = Pursuit Rotor, time on target

CC = Cube Comparison Test, number correct minus the number incorrect

TV = Television Handball, time to complete game

CONCLUSION

The results of both studies were positive, and there are some implications for future research. Study I showed that performance in the pursuit tracking task could be predicted by using a multiple regression approach with information-processing variables as predictors. In both training conditions, adaptive and fixed, time to exit performance was predicted reliably, as indicated by the double cross-validation results.

These results have implications for future research on individual differences in motor skill learning. Information-processing skills were found important in motor skill learning, and many of the mechanisms of various information-processing theories dealing with human performance could be tested. Furthermore, performance in other training models for motor skills could be predicted by generating new regression equations. Williges and Williges (1977) found success with a learner-centered training model for motor skill training. Other adaptive training models could be utilized with different adaptive logics. By adding more training strategies, a trainer could more closely match students with a training strategy. Finally, the prediction of motor performance may be improved by adding measures of personality characteristics, previous experience, general psychomotor skills, and task-specific variables. From the results reported here, it appears that successful prediction of transfer performance may be dependent on measures of task-specific variables. This is particularly true, since the I/E scale did not add to the prediction of transfer performance.

Study II results document that matching students to a training strategy results in substantial savings of training time. This was particularly true for female subjects. For the transfer task, smaller tracking error resulted when subjects were matched as opposed to mismatched.

Overall, three basic conclusions seem warranted. First, a methodological approach was utilized by using regression equations as a decision rule. The results of this research show that this approach is successful; however, it may not necessarily be the best approach. Future research is needed to determine the appropriateness of other approaches, such as the use of discriminant analysis or the approach suggested by Conway and Norman (1974). Furthermore, this research needs to be replicated, which is necessary to determine the validity of the methodological approach used in this research.

Second, individualized training is supported by this research in terms of training time and tracking error. In other situations, such as pilot training, individualized training can be costly, and certain trade-offs need consideration. Forty-five minutes of pretesting is not cost effective when the student can be trained in 30 minutes as with the tracking task used in the present research. If the training time is a matter of days or weeks, then 45 minutes of pretesting can have definite benefits for purposes of matching students with a training strategy.

Finally, this research can be thought of in terms of searching for an "optimal" training strategy for the individual, optimal used in the sense of matching as closely as possible the characteristics of the individual with a training strategy. Based on the results of this research, matching trainees with an "optimal" training strategy will result in a savings of training time and better performance in transfer. The possibility exists, however, that an individual is matched to a training strategy, but it may not necessarily be an "optimal" strategy. Therefore, research is needed to not only predict performance within a training strategy, but also to determine efficient and economic training strategies so that an "optimal" training strategy for the individual becomes more of a reality.

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Appendices Omitted

Appendix B

The Combined Effects of Various Types of Augmented Feedback and Two Training Procedures on Motor Skill Learning

THE COMBINED EFFECTS OF VARIOUS TYPES OF AUGMENTED FEEDBACK AND TWO TRAINING PROCEDURES ON MOTOR SKILL LEARNING

by

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INTRODUCTION

Background

Throughout the history of learning research, there has been no conclusive data to demonstrate that learning can occur without the presence of some form of feedback. In any given task, feedback is usually separated into two components, intrinsic feedback and augmented feedback. Intrinsic or fundamental feedback is that which is inherent in a system and is encountered in most daily tasks. For example, in driving an automobile, an increase in the loudness of the engine informs the operator that he is accelerating. However, the operator can not precisely tell you the speed at any one point in the acceleration. The speedometer provides this information and is a form of augmented or supplemental feedback since it is not inherent in the sub-system causing the automobile to accelerate.

Clearly, the augmented feedback is not essential to the system's operation, but it is obvious that the performance of the operator-machine system can be improved by its use. This is the basic difference between intrinsic and augmented feedback--intrinsic feedback is essential to the successful operation of a system, whereas the system may be operated without the use of augmented feedback. However, the appropriate implementation of augmented feedback into a system can lead to improved performance of the operator and, therefore, improve the operation of the system. Consequently, one could define augmented feedback as supplemental information provided to the human operator which enhances the fundamental feedback available from the operational system.

Although both forms of feedback are based on the same source of information, fundamental feedback is the more direct of the two in that the information in provides is immediate and does not undergo any transformations. Augmented feedback, on the other hand, is based on a sample of behavior taken over time and is transformed in the sense that the behavior of the operator-machine system is compared with an external criterion. In the above example, the sound of the engine is fundamental feedback because it is a direct result of the mechanical operations causing the automobile to accelerate. Since the speedometer represents the past actions of the operator and the information it presents is compared with a legally or individually established criterion, it is a form of augmented feedback. Thus, information supplied by the augmented feedback aids the operator to evaluate performance against established criteria. The means by which augmented feedback is generated and the way in which it is utilized by the operator indicates that it must occur some time after the operator's actions and that it has an evaluative function.

Figure 1 illustrates augmented feedback aiding the operator in evaluating performance. The operator compares system input (what should be done) with system output (what actually was done) and evaluates the results of operator actions against the external criterion.

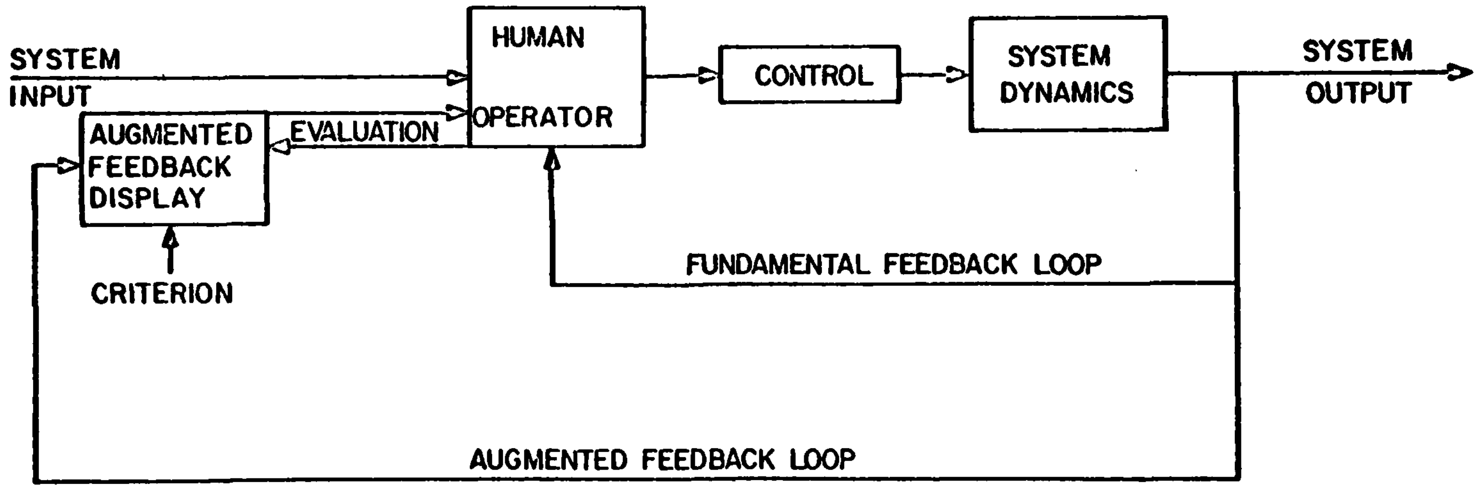

Figure 1. Fundamental and augmented feedback loops.

Augmented feedback does not always take the form of information presented on a display. It could very well be comments from an instructor, as is often the case in industrial training situations, or a paper and pencil test from which the trainer evaluates the trainee's progress and then feeds this information back to the trainee. Many training systems currently employ augmented feedback while many more could benefit from its use. However, augmented feedback is of no benefit if upon its withdrawal (such as the case may be in going from a job training situation to the actual job) the human operator's performance declines to the point that he can no longer successfully control the system.

Open-loop versus closed-loop systems. Most learning situations encountered are of the open-loop variety. An individual possessing a specified minimum aptitude is expected to complete successfully a task with a certain level of difficulty given an appropriate set of stimuli. In designing the learning situation, no consideration is usually given to feedback derived from the learner's responses. If feedback is incorporated into the system, it is typically of the reinforcement type, indicating performance degradation or improvement, which does little to aid the learner in formulating a correct response. Closed-loop learning systems differ in that a reference specifying the desired system response is available against which the system's output (feedback) due to the operator's responses are compared. Thus, the learner has a criterion on which to base successive responses if a discrepancy (error) occurs between the output of the system due to a previous response and the reference. These are two qualifying features of a closed-loop system--that it be error centered and that it have a reference mechanism against which feedback from a response can be compared for the detection and correction of error. In this regard, Bilodeau and Bilodeau (1961) point out that the central focus of an open-loop system is the correct response, whereas the central focus of a closed-loop system is error.

Until recently, all learning theories, including those of James (1890), Washburn (1916), Lashley (1917), Thorndike (1927), and Bartlett (1948) were open-looped in that they treated errors incidentally or only hinted at feedback being partically responsible for successive responses. Adams (1971) however, has proposed a theory of motor learning with error as its central focus. In Adams' theory, the reference mechanism or "perceptual trace" against which the correctness of a particular response is evaluated is developed and strengthened as a function of sensory feedback received from the responses. The perceptual trace is actually a motor image of past movements which the learner uses to compare against the feedback from each response. Differences between the perceptual trace and feedback from individual responses aid the learner in improving responses until discrepancies between the feedback and the perceptual trace eventually cease to exist. At this stage of learning, Adams maintains that the learner can now respond with respect to the perceptual trace alone and feedback concerning responses is no longer essential to the maintenance of adequate performance. Although he contends that feedback is no longer essential at this point in training, he also adds that the continuance of feedback in the transfer situation will enhance performance.

Even though no general agreement exists among motor-learning theorists as to the precise role of feedback in motor skill acquisition, they do agree that feedback concerning performance level is critical in the acquisition of a motor skill. Despite this fact, some training systems inherently eliminate much of the intrinsic feedback available to the trainee. The most popular of such systems are those that employ an adaptive logic.

Adaptive training systems are of interest to motor skills researchers since they provide a means by which motor skills training may be individualized. In open-loop training systems where task difficulty is maintained at a constant level throughout training, the task is often too easy at certain points in the training process for some trainees while being too difficult for others. In an adaptive training system, on the other hand, one or more variables important to the training task are changed according to the trainee's performance (see Figure 2). As the trainee's performance improves, the difficulty or complexity of the adaptive variable(s) is manipulated such that some measure of performance remains relatively constant throughout training. As a result of this adaptiveness of the training system, the learner's error remains relatively constant throughout training. Irrefutably, this is a closed-loop system in that its central focus is error and the trainee's performance affects the system's dynamics. However,

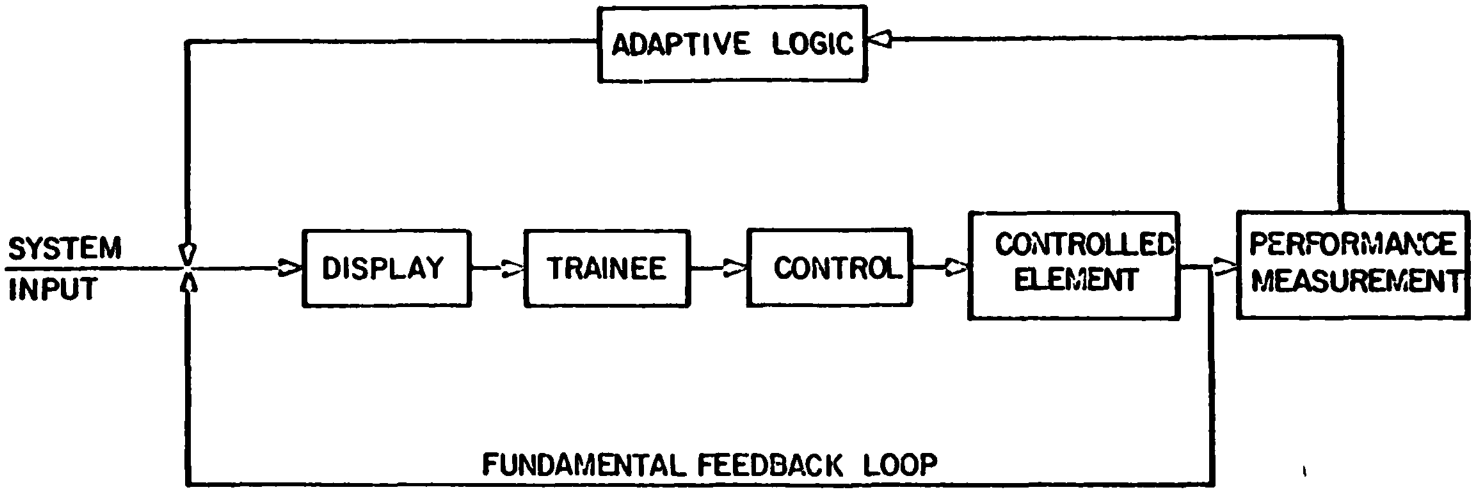

Figure 2. Schematic diagram of an adaptive training system.

error in a closed-loop system is to be used by the trainee in evaluating performance. In adaptive training systems, the error perceived by the trainee remains relatively constant, leaving little on which performance may be judged or future responses based. Kelley (1969), an innovator of adaptive training, recognized this fact and suggested (but did not experimentally test) that augmented feedback in the form of a meter indicating task difficulty level and possibly an indicator of out-of-tolerance performance be provided to trainees in adaptive training systems.

Augmented feedback in motor skills training. An extensive amount of research examining the effects of augmented feedback in traditional, open-loop motor skills training systems has been conducted, but the results have often been in disagreement with one another. Archer, Kent, and Mote (1956), Archer and Namikas (1958), and Bilodeau and Rosenquist (1964) found augmented feedback to have no effect on subjects' performance in training or transfer. Numerous other studies have found augmented feedback to aid performance in training but to have no effect on transfer performance when feedback is withdrawn (Morin and Gagne, 1951; Bilodeau, 1952; Goldstein and Rittenhouse, 1954; Bilodeau, 1955; Payne and Hauty, 1955; Karlin and Mortimer, 1963; and Sheldon and Bjorklund, 1966). Other researchers have found augmented feedback to produce a learning effect where the performance of the feedback groups remains significantly better than that of the no-feedback groups even after the augmented feedback is withdrawn (Reynolds and Adams, 1953; Smode, 1958; Williams and Briggs, 1962;

Kinkade, 1963; Karlin, 1965; Gordon and Gottlieb, 1967; and Gordon, 1968).

Although these studies have produced conflicting results, they have been valuable in formulating some general conclusions regarding the use of augmented feedback in open-loop motor skills training systems. Welford (1968) observed that supplemental feedback must not provide cues which are eventually relied upon to the extent that when the feedback is withdrawn, the trainee is no longer able to maintain adequate performance. A performance decrement upon feedback withdrawal has most often been found in systems where the trainee is capable of performing part of the task by simply attending to the supplemental feedback cues. When the supplemental feedback is withdrawn, a considerable amount of information loss occurs and performance deteriorates. Annett and Kay (1957) suggest that if such cues are to be used, the training situation should be arranged so that the extra cues, while aiding the trainee in the early part of training, later become redundant information. In this way, the trainee would no longer rely upon these cues in the later parts of training and, therefore, no serious decline in performance would occur upon their withdrawal. If one puts Annett and Kay's suggestion into perspective with Adams' (1971) theory of motor learning, it is apparent that Annett and Kay are suggesting the removal of these cues when the perceptual trace has been developed to the point that feedback is no longer essential to adequate performance.

The reliance upon supplemental feedback is most often encountered in predictable systems providing rather precise error information. Since error is relatively constant in adaptive training systems and augmented feedback would be more performance oriented, any such problems should be circumvented.

Clarity of the intrinsic feedback provided by the training task has also been found to be an important variable interacting with augmented feedback (Adams, 1964). If the intrinsic feedback in the training system is not clearly discernible, the additional feedback provided will become a part of the total information used to guide performance. Thus, the function of the augmented feedback will change from its intended purpose of aiding in the evaluation of performance to one of guiding performance. Kinkade (1963) found that subjects who received augmented feedback in a training task where the intrinsic feedback was ambiguous performed significantly better in training than subjects who did not receive augmented feedback. However, when feedback was withdrawn in transfer, the performance of the feedback group declined to that of the no-feedback group. In a similar training task in which the intrinsic feedback was clearly discernible, subjects provided with augmented feedback in training performed significantly better in training <u>and</u> transfer than subjects who did not receive augmented feedback in training. These findings are of importance in considering the implementation of augmented feedback into any training system.

Williams and Briggs (1962) concluded that the type of behavior indicated by augmented feedback is related to the effect it produces. With feedback indicating out-of-tolerance performance, large errors are emphasized early in training and the trainee learns to minimize them quickly. With feedback indicating in-tolerance performance, small errors are emphasized and the trainee is not as quick in responding to correct the large errors not emphasized by the feedback. Since minimizing out-of-tolerance performance is of primary importance in training, out-of-tolerance feedback would appear best in aiding the trainee to achieve the desired performance level.

Williams and Briggs (1962) also made the important observation that with feedback indicating out-of-tolerance performance, the amount of feedback received by the trainee diminishes as training continues. Thus, when the trainee is put into the transfer situation where feedback is not present, the change is not as abrupt. In their research, Williams and Briggs found that subjects who received out-of-tolerance feedback in training did not exhibit a performance decrement in the no-feedback transfer task. Subjects receiving in-tolerance feedback during training, however, failed to maintain their superiority over the control group that did not receive feedback in training. In addition, the in-tolerance feedback group displayed considerably greater inter-subject variability in transfer than the out-of-tolerance feedback group. These results are in agreement with the findings of Adams, Goetz, and Marshall (1972), which suggest that the performance decrement in going from the training to the transfer situation is least when the change in feedback is minimal.

Finally, Bilodeau (1966) and Annett (1969) suggest that augmented feedback should direct the attention of the trainees to the results of their responses and, thus, their errors. Out-of-tolerance feedback would appear to be best suited for this in that the trainees would be signaled when their responses are in error. In an adaptive training system, an indication of task difficulty would provide the trainees with similar performance information in that a decrease in task difficulty would indicate a performance decrement while an increase in task difficulty would indicate an improvement in performance.

In summary, research on traditional, open-loop motor skills training suggests that in order for augmented feedback to have a learning effect (i.e., to have the improved performance caused by augmented feedback to continue after the feedback is withdrawn), the following provisions must be made: (1) the augmented feedback must not provide cues which are relied upon for successful performance throughout training, (2) the intrinsic feedback provided by the training system must be clearly discernible, (3) the augmented feedback should signal out-of-tolerance performance, and (4) the augmented feedback should direct the attention of the trainees to the results of their responses and, thus, their errors. Although these results are the culmination of several years of research effort on traditional open-loop motor skills training systems, they can not be generalized to closed-loop forms of motor skills training without empirical testing.

Statement of the Problem

Research conducted on the effects of augmented feedback in closed-loop motor skills training systems has been scant. Norman (1973) is one of the few to have carried out such research. In a series of experiments, he provided subjects in an adaptive flight training task with visually augmented, level-of-difficulty feedback and found the visual feedback to have no effect on training performance. However, when the feedback was withdrawn in transfer, subjects who received feedback in training performed significantly better than those who were in the no-feedback training groups. Unfortunately, the reliability of these findings is somewhat questionable since the comparisons were made between groups in more than one experiment in which different subject pools were used, the independent variables differed, and the training task was substantially different from the transfer task.

Cote, Williges, and Williges (1978) conducted two studies on the use of augmented feedback in motor skill training using a two-dimensional pursuit tracking task. The purpose of this research was to evaluate the effects of visually presented augmented feedback on motor skills learning using either traditional, open-loop training or closed-loop training. Feedback in both studies was in terms of task difficulty and performance accuracy (see Figure 3). In Study I, the effects of augmented feedback cues on adaptive motor learning were examined using an automatic adaptive training procedure in which task

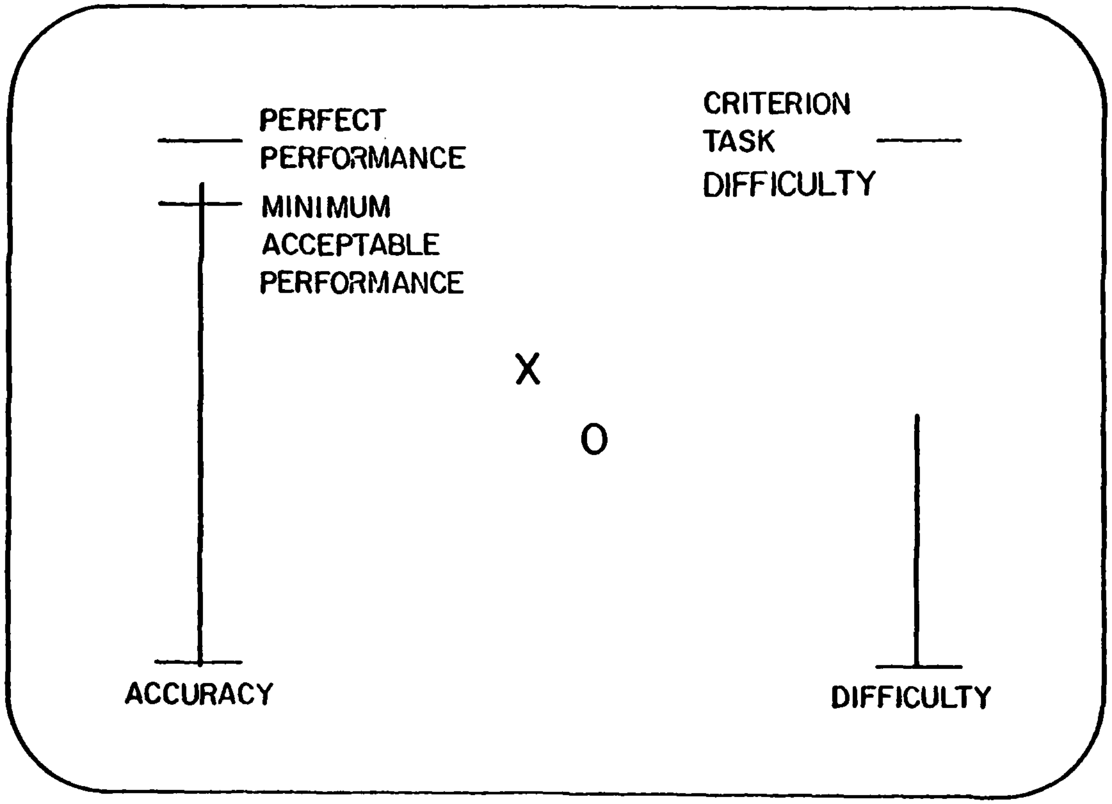

Figure 3. Two-dimensional pursuit tracking task with augmented feedback indicators. ("ACCURACY" and "DIFFICULTY" were the only labels displayed in the actual task).

difficulty increased as a function of the trainee's performance. Six male subjects were randomly assigned to each of the four treatment conditions presented in Table 1.

Although the mean training time-to-criterion scores of subjects who received augmented feedback was not significantly higher than that of subjects who did not receive the augmented feedback, there was a trend for the training scores of subjects who received feedback to be higher. A possible explanation for this may come from the comments of several subjects who mentioned that when they attempted to use the augmented feedback, their tracking performance declined sharply. In transfer, no reliable effects due to feedback in training and/or transfer were observed ($p > 0.10$).

In Study II, the combined effects of visually presented augmented feedback and training procedure were examined. Two training procedures were used: (1) a fixed-difficulty procedure in which the trainee was presented with the criterion level of task difficulty throughout training, and (2) the automatic adaptive training procedure used in Study I.

Six male subjects were randomly assigned to each of four training/feedback conditions. These were: (1) a fixed-difficulty procedure in which no augmented feedback was presented, (2) a fixed-difficulty procedure in which visual augmented feedback was presented, (3) an automatic adaptive procedure in which no augmented feedback was presented, and (4) an automatic adaptive procedure in which visual augmented feedback was presented. A transfer task similar to the

TABLE 1

Treatment Combinations of Study I

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

training task was given to all groups in which feedback was not presented. Results of the analysis of variance indicated no difference in training time-to-criterion ($\underline{p} > 0.05$). 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. However, subjects who were trained adaptively performed reliably better in transfer than those receiving fixed-difficulty training ($\underline{p} = 0.0065$). The presence of feedback in training did not prove to have any effect on transfer performance ($\underline{p} > 0.10$).

The results of the above two studies imply that constantly presented 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 training results of Study I and the comments of several subjects in the feedback conditions, there was reason to believe that the training task in these two studies imposed such a large visual workload upon the subjects that they were unable to use the feedback effectively. In fact, the visual workload of the subjects in the feedback conditions was theoretically increased by providing them with the visual feedback.

If the workload imposed by a task is such that the augmented feedback can not be attended to, then the feedback will not have an effect on training performance. With this being the case, one can not expect transfer performance in a non-augmented feedback condition to be affected either. This has been a consistent finding of augmented feedback research in which augmented feedback failed to enhance behavior while present in training.

Thus, a primary concern when employing augmented feedback should be its capability of being used by the trainee. In relatively simple systems, this criterion may be met by presenting augmented feedback in any one of numerous ways. However, the more complex the training system, the more careful one must be in presenting augmented feedback so that it is useful. For example, in complex training systems outside of the laboratory, a high visual workload is often encountered. Some systems require the operator to constantly monitor numerous continuous information displays which provide information important for successful task performance. One such instance is a flight training simulator. In situations such as this, it is imperative that means other than the constant presentation of visual feedback be explored if, indeed, this augmented information is capable of aiding performance.

Some research in this area has recently been conducted. Gibson and Ventola (1976) successfully employed constantly augmenting tactile feedback to present pilots with flight path information during approach and landing operations. Lintern (1978) presented adaptive visual flight path information during landing operations that appeared only when the trainee was off-course. As in Gibson and Ventola's study, Lintern found a performance as well as a learning effect attributable to the augmented feedback.

Purpose of Thesis Research

Research dealing with the effects of augmented feedback on closed-loop motor skills training has been severely limited. Furthermore, little has been done to investigate alternative procedures for presenting augmented feedback in complex motor skills training. The purpose of the present research was to evaluate the effects of two types of off-course augmented feedback using two training procedures on the learning of a complex motor skill.

The main point of interest in this study was the effect of the augmented feedback on adaptive motor skill learning. The types of feedback used were: (1) auditory feedback, (2) visual feedback, (3) auditory plus visual feedback, and (4) no feedback. Two training procedures were used to assess whether or not the various augmented feedback types would have any differential effects upon training procedure. The training procedures used were: (1) a fixed-difficulty training procedure representing traditional, open-loop motor skills training, and (2) an adaptive training procedure.

With the use of off-course augmented feedback, the amount of information presented diminished as training progressed. This prevented an abrupt change in the amount of information available from occuring in the transition from training to the no-feedback transfer condition. Furthermore, off-course feedback called attention to and emphasized one's errors early in training. In addition to these desirable qualities, off-course information, if correctly implemented, has a clear advantage over continuous augmented information in that it does not require constant monitoring.

Besides off-course information, subjects who received feedback in the adaptive training procedure also were provided information concerning the changing levels of task difficulty. The decision to include such information was the result of a suggestion by Kelley (1969). With error remaining relatively constant in an adaptive training system, Kelley suggested that it is important for the trainee to be provided with some type of information indicating performance improvement.

It was hypothesized that the augmented feedback would produce a performance as well as a learning effect in both types of training procedures used. It was also hypothesized that subjects who received adaptive training and augmented feedback would have lower training scores than subjects in the fixed difficulty conditions receiving augmented feedback. Providing level-of-difficulty feedback with adaptive training eliminates the problem of there being no performance information in adaptive systems. Thus, the combination of the adaptive procedure which provides tailored training and level of difficulty feedback which provides performance information, training should be facilitated in terms of lower time-to-criterion scores. Finally, it was hypothesized that those who received adaptive training would perform significantly better in the transfer task with multiple levels of task difficulty than those who received fixed-difficulty training. This hypothesis was based on the fact that subjects presented with the adaptive training procedure have more experience in tracking the forcing function at various levels of difficulty and therefore could more readily adapt to changing levels of task difficulty in transfer.

METHOD

Tracking Task

To investigate the possible facilitating effect of augmented feedback in motor skills training, a two-dimensional pursuit tracking task was used. The experiment was divided into two sessions, a training session and a transfer session, with the same tracking task being used in both sessions.

Training task. Subjects learned the two-dimensional pursuit tracking task illustrated in Figure 4. Three 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 a movement in each axis and the duration of the vector movement. The forcing function of the tracking symbol ("O") was generated from the output of an isometric control stick.

The effective tracking area on the display was 12.7 cm X 12.7 cm with the visual feedback appearing outside of this region (8.89 cm from the display's center). Subjects rested their heads on a forehead rest such that the viewing distance was kept constant at 1 m. With this viewing distance and a subject's point of regard being the center of the display, the visual angle subtended by the feedback bars was 10.1°. Thus, the feedback bars were in peripheral vision when a subject fixated on the center of the display. Each tracking symbol presented on the display occupied a 0.64 cm X 0.48 cm area.

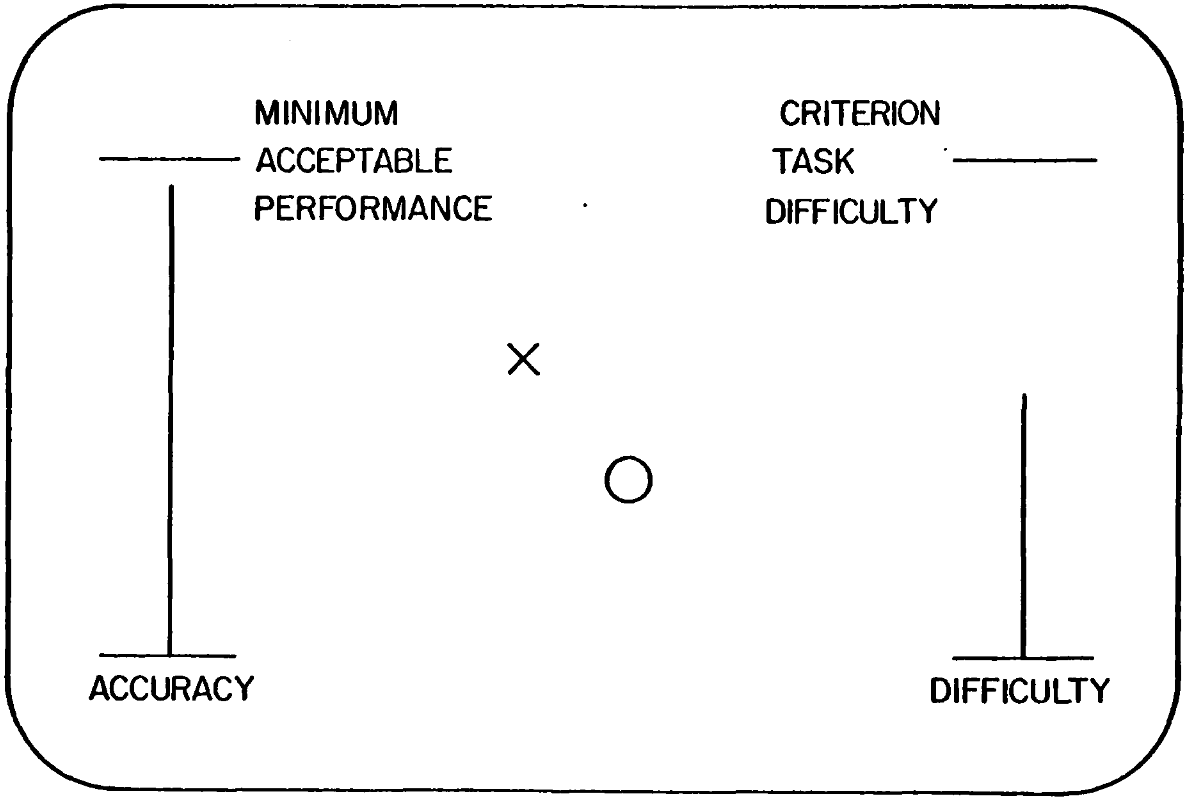

Figure 4. Two dimensional pursuit tracking task with visual augmented feedback. ("ACCURACY" and "DIFFICULTY" were the only labels displayed in the actual task).

The control system dynamics of this system were neither pure rate nor pure acceleration. With pure acceleration system dynamics, pretesting results showed mean time to be more than 1 h, a time period longer than that desired by the experimenter. In pretesting subjects with a pure rate system, mean training time was less than 5 min with little intersubject variability. Thus, various weighting constants were placed on both control orders and several new subjects were pretested to establish weightings that would result in training times acceptable to the experimenter and also yield satisfactory intersubject variability.

For each stick output, the corresponding positions of the "O" under both pure rate and pure acceleration control were calculated. The following transfer function describes the system dynamics in each axis:

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

where Θ_{ox} (S) = the Laplace transform of the scalor 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.

For this experiment, α was specified equal to 0.8. The constants K_1 and K_2 were derived as a function of the maximum allowable speed of the "O" set in the task parameters (see Appendix A) and the effective tracking area on the display. These constants were specified as follows:

$$K_1 = 1.4511 \text{ cm s}^{-1} \text{ N}^{-1}$$
$$K_2 = 1.6 \text{ s}^{-1}$$

The input force was that applied to the top of the 12.54 cm isometric controller and measured at its base.

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. In Equation 2, Θ_{ix} would be the simulated control stick output value. The K_i constants for the pursuit symbol were derived as a function of the maximum and minimum velocities of the "X" set in the parameters of the task and the effective tracking area on the display. These constants were specified as follows:

$$K_1 = 0.7246 \text{ cm s}^{-1} \text{ N}^{-1}$$
$$K_2 = 0.8 \text{ s}^{-1}$$

The value for the input force in newtons was chosen from a random number generator internal to the mini-computer 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.

A small-step adaptive logic was available to vary task difficulty by changing the maximum allowable output value of the simulated control stick. Absolute vector tracking error was computed every 60 ms and compared to a tolerance limit of 10% of the screen diagonal (1.8 cm). A total of 1851 task difficulty steps requiring a minimum time of 111.1 s to reach the exit criterion level of difficulty was used. With such a small-step adaptive logic, performance was stabilized throughout training, but increases in level of task difficulty were not readily apparent from the task itself.

The criterion level of task difficulty during training was a maximum possible movement speed of the "X" of 20.32 cm/s. In the fixed-difficulty training procedure, the speed of the "X" was maintained at the criterion level throughout training. Exit criterion training performance was the maintenance of the "O" within 10% of the effective screen diagonal of the "X" for a period of 20 continuous seconds while the "X" was moving at the criterion level of difficulty. To avoid confounding fatigue effects, subjects were given a maximum of fifteen, 3-min trials interspersed with 1-min rest periods to exit the training task.

<u>Transfer task</u>. After training to criterion and a 5-min rest period, subjects were given a 6-min transfer task identical to the training task with the exception that no feedback was presented to any of the groups. Task difficulty shifted among three levels with each level of difficulty being presented for 2 min. These three levels of difficulty were: the exit criterion level of difficulty in training

(20.32 cm/s), 0.5 X exit criterion level (10.16 cm/s), and 1.5 X exit criterion level (30.48 cm/s). The presentation of the levels of difficulty was completely balanced within each cell, yielding six possible presentation orders. With there being 12 subjects per cell, two subjects in each cell received the same presentation order.

Experimental Design.

Figure 5 contains a block diagram of the experimental design. The two factors examined in training were training procedure and augmented feedback. Training procedure had two levels with one being adaptive training (closed-loop) in which the level of task difficulty varied as a function of the trainee's performance according to the logic described in the training task and the other being fixed-difficulty training (open-loop) in which the trainee was presented with the criterion level of task difficulty throughout training. The second factor examined in training, augmented feedback, had four levels. These four levels included two different types of off-course feedback (visual and auditory), a combination of both types of off-course feedback, and no augmented feedback.

Visual feedback was provided as shown in Figure 4. On the left hand side of the display appeared a bar graph labeled "ACCURACY." The horizontal line at the top of the bar graph indicated in-tolerance performance, or, the "O" being 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 the

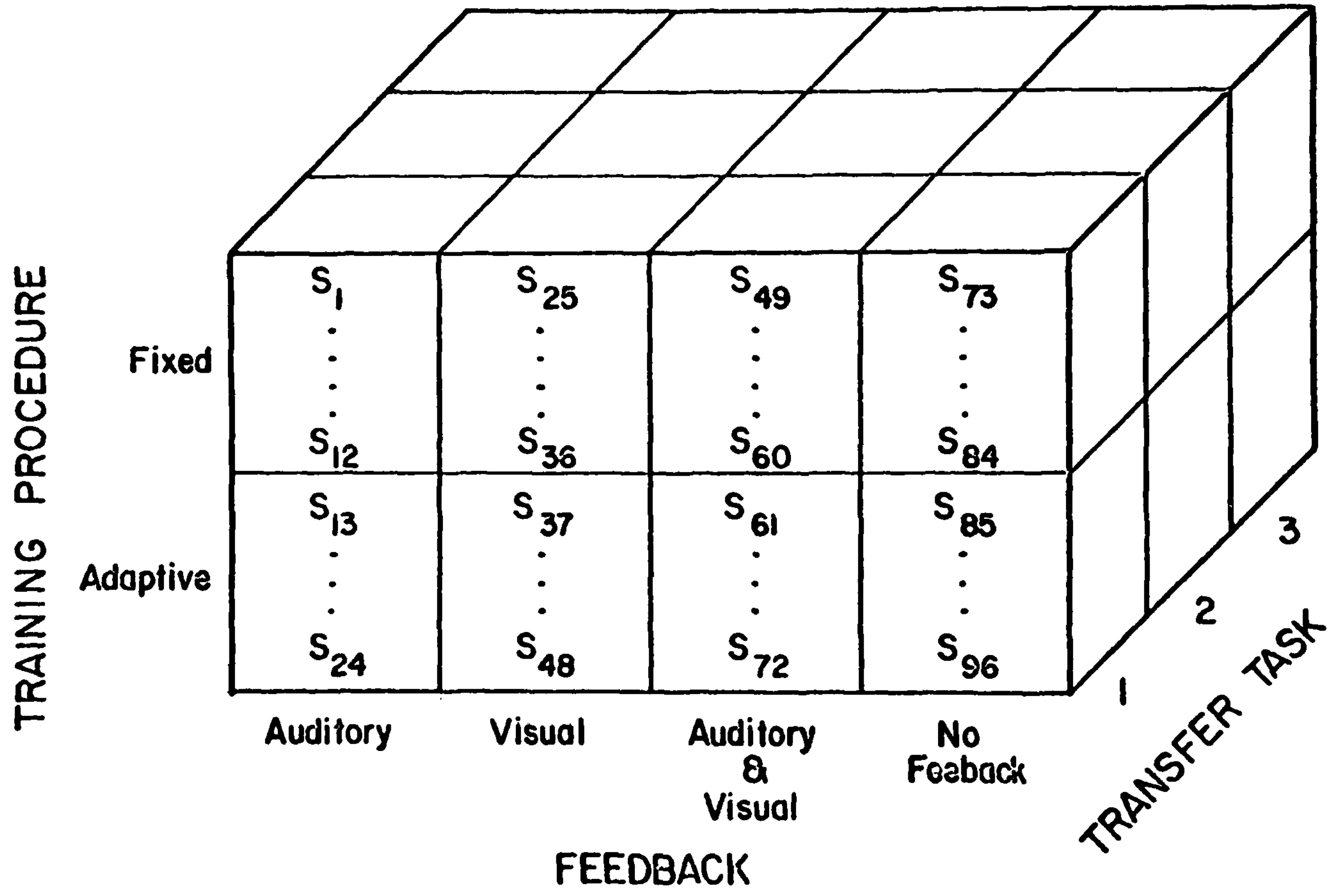

Figure 5. Block diagram of experimental design.

subject moved the "O" outside of the tolerance range, the bar reappeared on the display. On the right hand side of the display appeared a bar graph labeled "DIFFICULTY." As task difficulty increased, the bar approached the upper horizontal line which indicated criterion task difficulty. When criterion task difficulty was achieved, the right hand bar graph disappeared from the display. In the adaptive training procedure, the bar graph reappeared if a subject's performance became out-of-tolerance after the criterion level of difficulty had been reached. In the fixed-difficulty training procedure, this bar graph was not presented because task difficulty was always at the criterion level.

Auditory feedback was provided through a loudspeaker located approximately 1.5 m to the rear and 1.5 m above the subjects. Task difficulty was indicated by 50 ms "beeps" at 400 Hz and 46 dB. When the task was at its lowest level of difficulty (as it was when training began), the beeps were presented at the rate of 20/s and were perceived as a continuous tone. As task difficulty increased, the period between beeps also increased until the criterion level of task difficulty was reached. At this point the beeps were no longer presented. However, if performance decrement occurred and task difficulty decreased, the beeps reappeared at an initial rate of one beep every 400 ms. If performance decrement continued to occur, the rate of the beeps continued to increase.

Tracking accuracy was indicated by a continuous, 2,000 Hz tone varying in amplitude from 46 dB to 51 dB. When the "O" was more than

10% of the effective screen diagonal away from the "X" for a period of 60 ms, onset of the tone occurred at 46 dB with the tone increasing in amplitude to 51 dB when the subject was $\geq$ 50% of the effective screen diagonal away from the "X". All frequencies and amplitudes were selected such that no masking occurred.

As can be seen, the off-course feedback employed in this study was such that it was noticable when presented and therefore did not require the subject to perform a secondary task of monitoring for its presence. Furthermore, although the on-target versus off-target augmented feedback may have been redundant information in that this information was readily available from the task itself, the task difficulty augmented feedback given in the adaptive training procedure provided information not readily apparent from the task due to the small-step adaptive logic employed.

Equipment

The tracking task was generated using a laboratory developed software package run on a Digital Equipment Corporation PDP 11/55 digital computer. The task was displayed on a Tektronix 4014-1 computer display terminal. Subjects tracked the pursuit symbol using a Measurement Systems Model 435 two-axis isometric control stick. Augmented feedback was presented visually on the Tektronix display and auditorily through a Utah 15.24 cm, general purpose loudspeaker. The hardware responsible for generating the auditory signals was built in-house.

For the 2,000 Hz continuous tone indicating in-tolerance versus out-of-tolerance performance, an analog voltage was sent from the D/A converter of the PDP 11/55 (a DEC LPS 11) which was proportional to the subject's distance (in terms of percent of screen diagonal) from the pursuit symbol. This voltage was received by a voltage control amplifier which also had a 2,000 Hz input. If the voltage received corresponded to a subject's tracking error being greater than 10% of the screen diagonal (out-of-tolerance performance), the voltage control amplifier amplified the 2,000 Hz input to a specific dB level between 46 dB and 51 dB and sent it to another amplifier which powered the Utah speaker. If subject error was less than 10% of the screen diagonal, no auditory signal was generated.

The beep rate of the 400 Hz tone was generated as the result of a digital output of the LPS 11. A 16 bit word with a numeric value corresponding to task difficulty level was received by a counter with a continuous clock input. Given the digital signal and the input from the continuous clock, the counter determined when to send a signal to a trigger which opened a circuit to a 400 Hz input. (Upon signaling the trigger, the counter was reset). A 400 Hz output with a specific amplitude and duration was then sent to the same amplifier which powered the Utah speaker for the 2,000 Hz tone. So that both auditory signals could be put through the same speaker, an analog adder was employed. Thus, before either auditory signal was fed into the speaker amplifier, they were sent through the analog adder.

Figure 6 illustrates the experimental set-up. The software package responsible for generating the tracking task and the augmented feedback used two independent real-time cycles--a 60-Hz cycle to refresh the display and a 60-ms cycle to update the task and the augmented feedback. Figure 7 gives an overview of the software package while Figure 8 contains a flow diagram of the real-time process. Appendix C contains a listing of the software package.

Subjects

Twelve paid volunteer male college students were randomly assigned to each training/feedback condition for a total of 96 subjects. All were right-handed and naive to the experimental task. Before participating in the study, all subjects were given a full vision test with a Bausch and Lomb Orthorater and were required to have at least 20/25 vision (near and far, corrected or uncorrected). Furthermore, all subjects read and signed a consent form to participate in the study which delineated their rights as a subject. Subjects were given the opportunity to receive a summary of the experimental results by indicating so on the consent form. Appendix D contains the summary. Only male subjects were used to eliminate any sex differences that may exist in motor skills training (Williges, Williges, and Savage, 1977).

Procedure

Subjects were seated in the experimental room and given sufficient time to adapt to the room's low illuminance level. They were then

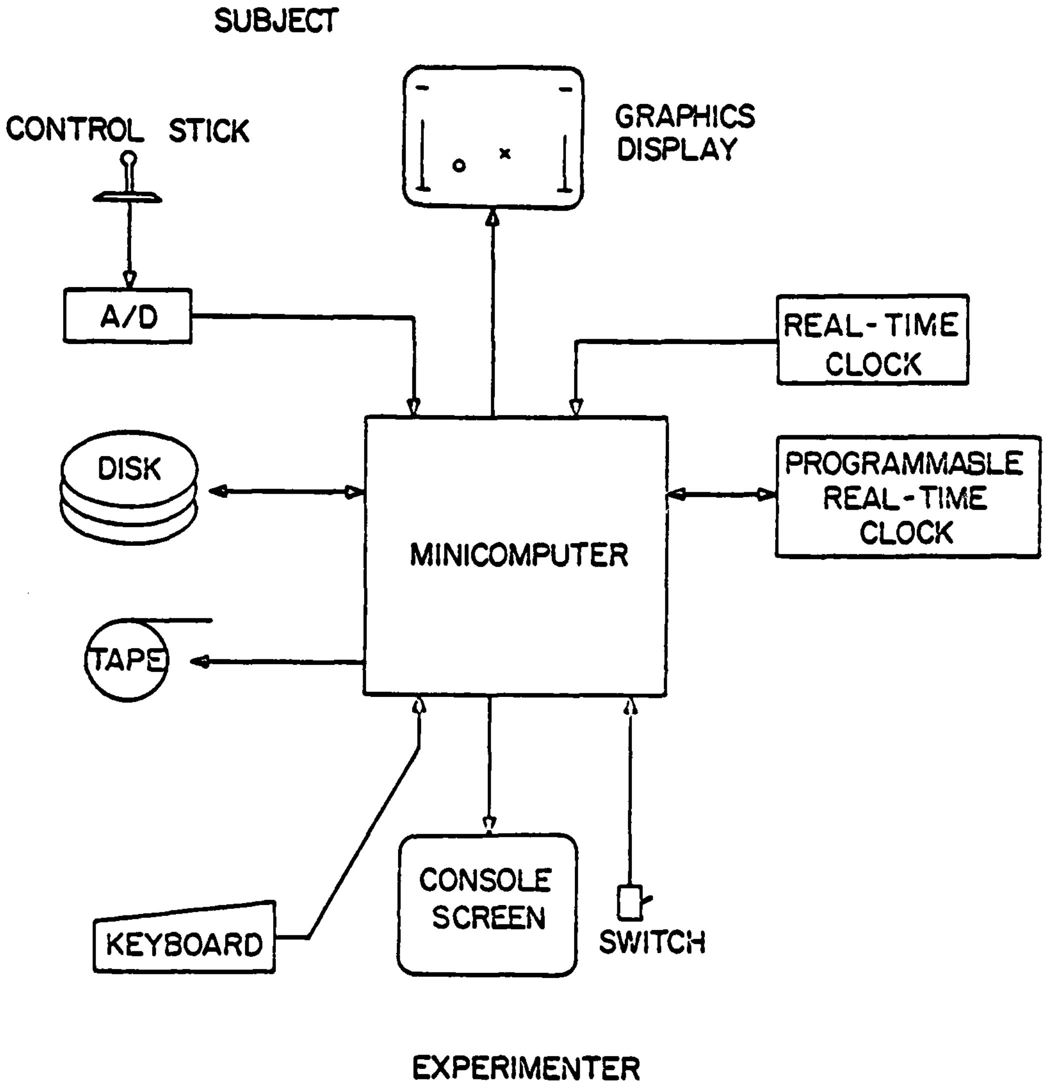

Figure 6. Experimental set-up.
(Prepared by John Evans, III).

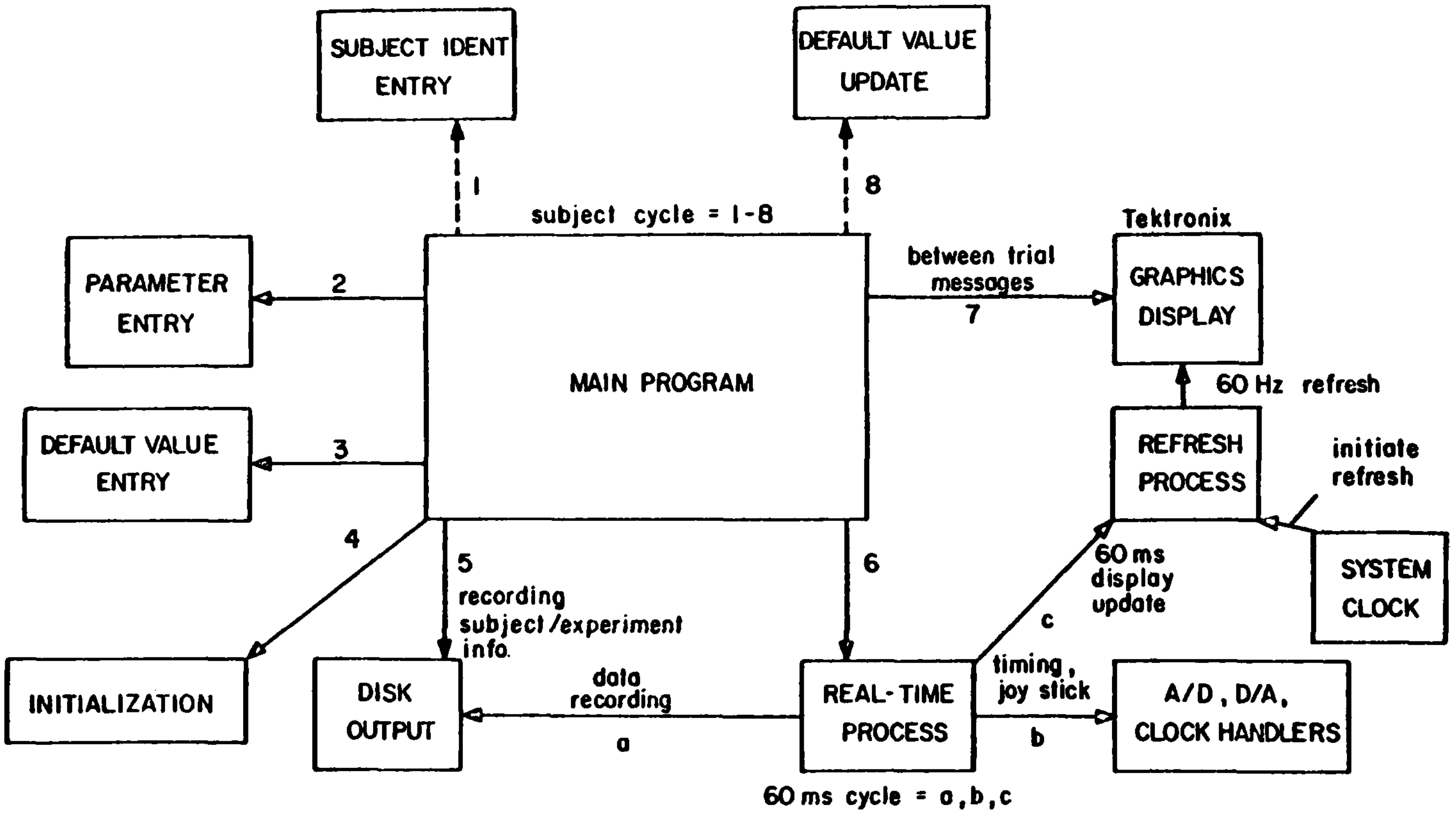

Figure 7. Software package.
(Prepared by John Evans, III).

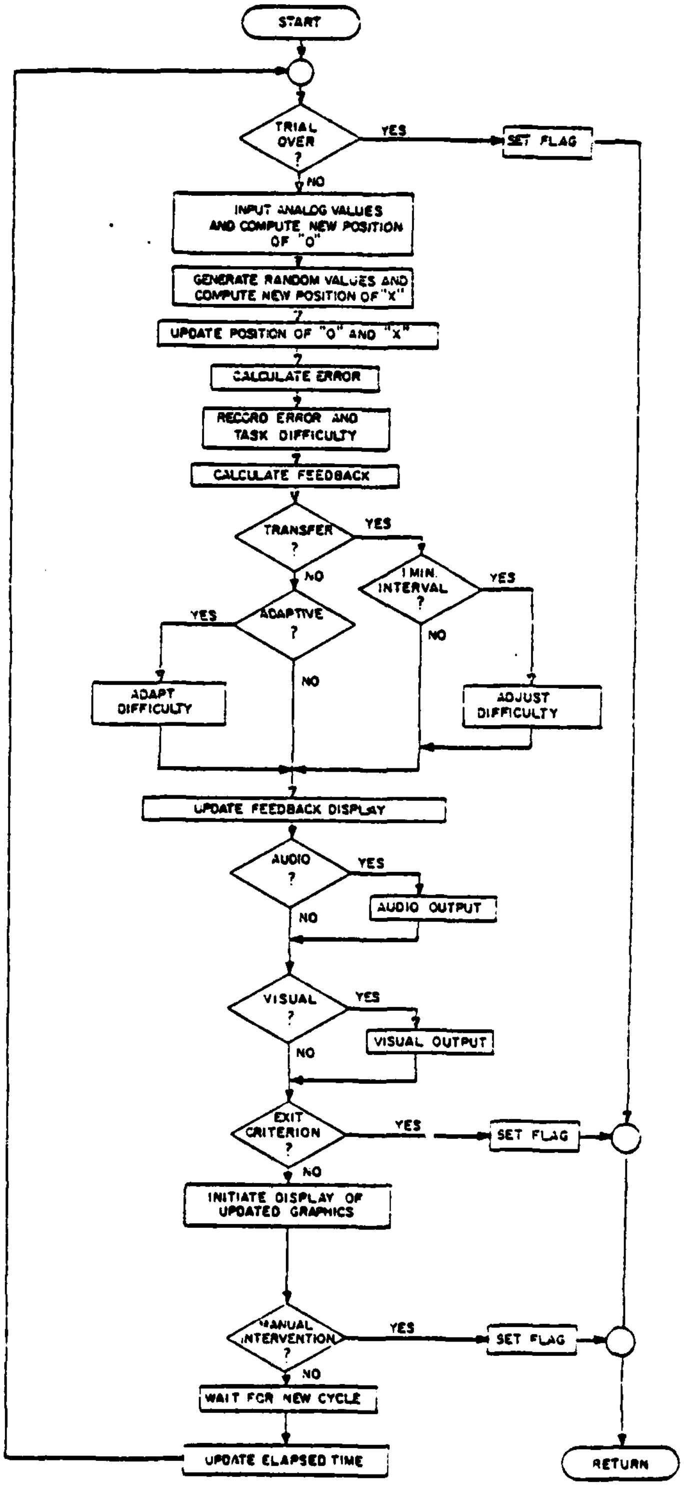

Figure 8. Flow diagram of the real time process.
(Prepared by John Evans, III).

given tape-recorded instructions appropriate to their respective experimental conditions. After attending to the recording, subjects were given the opportunity to ask questions concerning the instructions. The experimenter remained in the experimental room for the first trial of the training session after which the subjects were once again asked if they had any questions. For the remainder of the experiment, the experimenter resided in an adjacent room to which the subjects were provided communication via an intercom system.

RESULTS

Eight subjects failed to exit from the training task in the allotted 15 trials. Three were in the fixed-difficulty without augmented feedback condition while each of the following conditions had one no-exit subject: adaptive training with auditory feedback, adaptive training with visual feedback, fixed training with auditory feedback, fixed training with visual feedback, and fixed training with auditory and visual feedback. Thus, a total of 104 subjects were required to balance each of the right conditions with 12 subjects. Three χ^2 analyses were performed with the no-exit frequency data to determine if there was a significant difference in the number of no-exit subjects due to training procedure, type of augmented feedback or training/feedback conditions. None of the three analyses yielded significant results ($p > 0.10$). It must be noted, however, that a bias in favor of failing to reject the null hypothesis was introduced in those analyses in that some of the expected cell frequencies were less than 5 (Lewis and Burke, 1949). As a result, the probability of occurrence of the alternative hypothesis (there being a significant difference in the number of no-exit subjects due to training procedure, type of augmented feedback or training/feedback conditions) was actually higher than that obtained by these analyses.

All subjects were presented the transfer task, whether or not they exited from training within the allotted 15, 3-min trials. Equal n's analyses of variance as well as unequal n's analyses of variance were performed on the data. In the unequal n's analysis of variance on the training data, 45 min was used as the time-to-criterion for subjects who failed to exit from the training task. The unequal n's ANOVA used was Yate's (1933) weighted squares of means technique in which values for the missing observations in each cell are inserted so as to obtain a complete set of data. This technique yields inflated treatment F-values, but the inflation of these F-values is modest when the fraction of observations inserted in each cell is small relative to the total number of cell-observations used in the analysis. The significant findings in the unequal n's analyses were the same as those in the equal n's analyses. (See Appendix G for the ANOVA summary tables of the unequal n's analyses). Thus, the values reported are those of the equal n's analyses.

Training

Table 2 lists the mean time-to-criterion scores and their standard deviations for the eight training/feedback groups. A two-way analysis of variance on time-to-criterion scores yielded no reliable effect due to training procedure or augmented feedback on training time ($\underline{p} > 0.25$). Table 3 presents the ANOVA summary table of the training analysis.

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

TABLE 2

Mean Time-to-Criterion Scores and Standard Deviations

Condition	$\bar{X}$ (min)	s (min)
Fixed training/Auditory feedback	14.3	7.7
Fixed training/Visual feedback	13.4	7.1
Fixed training/Auditory plus visual feedback	12.0	8.7
Fixed training/No feedback	17.0	9.8
Adaptive training/Auditory feedback	14.6	9.3
Adaptive training/Visual feedback	14.2	9.8
Adaptive training/Auditory plus visual feedback	15.3	11.3
Adaptive training/No feedback	17.7	6.8

$\bar{X}$, Fixed training: 14.2 min

$\bar{X}$, Adaptive training: 15.4 min

$\bar{X}$, Feedback: 14.0 min

$\bar{X}$, No feedback: 17.4 min

TABLE 3

ANOVA Summary Table for Equal n Training Data

Source	df	SS	F	p
Training Procedure (T)	1	146005.08	0.51	0.4776
Feedback Type (F)	3	761279.64	0.88	0.4548
T x F	3	119049.35	0.14	0.9332
S/TF	88	25261347.63		
Total	95	26287681.70		

transfer as factors. Table 4 provides a summary of the mean error and standard deviation for the right training/feedback groups.

The main effect of level of difficulty was significant ($p < 0.0001$), indicating that the three levels of task difficulty presented in transfer did represent different skill levels (see Table 5). Tracking error increased with greater task difficulty (6.4%, 9.4% and 12.3%, respectively).

A more important result from the analysis of variance was the finding that training procedure had a significant effect ($p = 0.0251$) upon transfer performance. The mean vector error of those trained adaptively was 9.0%, whereas the mean vector error on those trained in the fixed-difficulty condition was 9.7%. The main effect of feedback in training and none of the interactions were reliable.

Questionnaire

A χ^2 analysis was performed on the cumulative responses to each response on the questionnaire. A summary of the χ^2 analysis on all questions is provided in Appendix F. Several of these findings are of primary interest.

Of the 72 subjects who received some form of augmented feedback, only two, a significant minority, responded that they did not employ it in performing the task, χ^2 (1) = 64.2, $p < 0.005$. Out of the 70 subjects who used the feedback, a significantly greater number said they found the feedback to be more than "helpful" on the questionnaire they were administered, χ^2 (1) = 16.5, $p < 0.025$. However, in an analysis by condition on the helpfulness

TABLE 4

Transfer Vector RMS Tracking Error and Standard Deviations

Conditions	Mean Error (% of screen diagonal)	s
Fixed/Auditory	9.2	2.6
Fixed/Visual	9.3	2.8
Fixed/Auditory plus Visual	10.1	3.5
Fixed/No Feedback	10.4	4.0
Adaptive/Auditory	9.1	3.0
Adaptive/Visual	9.0	3.1
Adaptive/Auditory plus Visual	9.3	3.0
Adaptive/No Feedback	8.6	3.0

$\bar{X}$, Fixed Training: 9.7%

$\bar{X}$, Adaptive Training: 9.0%

$\bar{X}$, Feedback: 9.3%

$\bar{X}$, No Feedback: 9.5%

TABLE 5

ANOVA Summary Table for Equal n Transfer Data

Source	df	SS	F	p
Between Subject				
Training Procedure (T)	1	0.0041	5.19	0.0251
Feedback Type (F)	3	0.0015	0.65	0.5870
T x F	3	0.0030	1.26	0.2942
S/TF	88	0.0698		
Within Subject				
Level of Difficulty (LOD)	2	0.1667	349.12	0.0001
LOD x T	2	0.0005	1.16	0.3155
LOD x F	6	0.0005	0.34	0.9162
LOD x T x F	6	0.0025	1.75	0.1114
LOD x S/T	176	0.0420		
Total	287	0.2906		

rating, it was found that the condition a subject was in significantly affected the helpfulness rating, χ^2 (15) = 29.8, $p < 0.025$. Approximately one-half of those subjects who received the fixed training with visual feedback and the adaptive training with both types of feedback found the augmented feedback less than "helpful."

Another interesting, statistically significant finding was subject preference to feedback type. Significantly more subjects indicated that they preferred auditory to visual feedback, χ^2 (1) = 8.16, $p < 0.005$. However, this preference was significantly affected by training procedure, χ^2 (1) = 6.32, $p < 0.005$, with all subjects in the fixed-difficulty training procedure preferring auditory feedback while only 7 subjects (58.3%) in the adaptive training procedure preferred the auditory feedback.

In addition to the above significant findings, some non-significant findings also proved to be interesting. A major concern of many experimenters in employing augmented feedback is its motivating effects. However, in responding to a question asking subjects how interesting they found the experiment, those who received feedback found the experiment no more interesting than subjects not provided with feedback ($p > 0.10$). Another interesting nonsignificant finding was that the actual use of the auditory signal, as indicated by the subjects, was not greater than that of the visual signal ($p > 0.10$) even though a significantly greater number of subjects preferred the auditory signal over the visual signal.

DISCUSSION

Augmented Feedback

Training. In training, no significant effect due to augmented feedback was found. This result is consistent with earlier findings of Cote, *et al*. (1978). However, the results of this study do not support the hypothesis that the lack of an augmented feedback effect with this task is due to a visual information overload. In the present study, the visual attention required to attend effectively to the visual feedback was minimal. Furthermore, the auditory feedback required no visual attention.

One could hypothesize that the lack of a feedback effect could be the result of an overall operator information overload, but this hypothesis is not consistent with the findings of the questionnaire analyses. If the augmented feedback created an information overload, it would appear reasonable to assume that subjects would ignore the feedback since the task could be performed without it. However, of the subjects who received augmented feedback, a significant majority said they used it in performing the task ($p < 0.005$). Furthermore, of the subjects who used the feedback, a significant majority considered it to be more than helpful ($p < 0.005$). In addition, over 50% of the subjects receiving feedback indicated that they used it for at least two-thirds of the training session.

Another interesting point from the questionnaire regarded the preference of feedback type and actual performance when presented with a single feedback type. When subjects who were presented with auditory and visual feedback in both training procedures were asked which feedback type they would choose if they had to do the same task again (see question 14 in Appendix D), a significant majority chose auditory feedback ($p < 0.005$). Nevertheless, subjects who received only the auditory feedback in both the adaptive and fixed-difficulty training procedures did not have significantly lower time-to-criterion scores than subjects who received only the visual feedback.

Transfer. As in the results of the training analysis, no significant effect due to feedback was found in transfer. The lack of any significant effect due to feedback in training and/or transfer was not expected. Gordon (1968), Gordon and Gottlieb (1967) and Williams and Briggs (1962) have all shown out-of-tolerance augmented feedback to produce a performance as well as a learning effect when used with open-loop tasks having clearly discernible intrinsic feedback. The intrinsic feedback available from the task used in this study was certainly clearly discernible. However, Michelli (1966) may offer an explanation for the differences in results. In varying the amount of augmented feedback presented and the discernibility of the intrinsic feedback, he found only a tendency for small amounts of information from augmenting feedback during training to be somewhat beneficial in transfer with tasks having clearly discernible intrinsic feedback.

Although the augmented feedback in the fixed-difficulty closed-loop task was usable, it did not provide information that was not readily available from the task itself. This may help explain the nonsignificant transfer results. However, in the transfer results of the adaptive training groups, a tendency of the feedback groups to perform better in transfer is evident. The lack of a significant result could be due to the small amount of additional information provided by the augmented feedback which was not intrinsically available from the task (task difficulty information).

Another plausible explanation for the finding of a learning effect in other studies employing off-course feedback and tasks with clearly discernible intrinsic feedback may be that of negative reinforcement. Since the augmenting cues were only presented when a subject's response was incorrect, an aversive conditioning effect may have occurred. Payne and his associates (Payne, 1970; Payne and Artley, 1972; Payne and Dunman, 1974; and Payne and Richardson, 1972) have shown that the pairing of an out-of-tolerance augmenting cue (red light) with an aversive stimulus (shock) prior to performing the actual training task with clearly discernible intrinsic feedback will cause the augmenting cue to produce a performance as well as a learning effect. Groups that did not receive the aversive conditioning prior to performing the task failed to show any tendency of a performance or learning effect due to the augmented feedback.

Training Procedure

Training. In training, no significant effect on time-to-criterion scores due to training procedure was found. This is consistent with the earlier findings of Cote, et al. (1978). However, it was hypothesized that the training by feedback interaction would be significant due to the adaptive procedure which provides tailored training and the level-of-difficulty feedback which provides performance information. This hypothesis was based on the results of numerous studies where adaptive training has not been found to be superior to fixed-difficulty training and Kelley's (1969) suggestion that the failure of adaptive systems may sometimes be due to their inherent lack of performance information. The provision of level of difficulty information appears to be especially important in adaptive systems employing a small-step adaptive logic in that performance improvement is then difficult to detect. However, the results of this study in which a small-step adaptive logic was employed fail to support this hypothesis.

The failure of augmented feedback to improve the performance of those in the adaptive training procedure may have been due to a couple of features inherent to the task. In the adaptive system used, task difficulty was adjusted in accordance with the trainee's performance in an effort to keep the trainee's tracking error relatively constant at a specified low level. As a consequence, though, behavior producing out-of-tolerance performance one moment would not cause out-of-tolerance at a time in the near future. Thus, the nature of the adaptive system could have voided any useful purpose that the out-of-tolerance feedback may have served.

Another reason for the failure of augmented feedback to have an effect on the performance of those trained adaptively may have been the subjects' knowledge of the amount of time they were to spend performing the task. Subjects knew that the experiment was approximately one hour in length. As a result, they may have been simply performing the task without giving much attention to the information they were presented regarding their performance. Thus, the information may not have been as important to them as it would be in a task that is open-ended. In a task that is not readily learned, requiring training to take place over an extended period, information indicating actual performance level in relation to criterion performance level could play an important motivational or incentive type role. In an extended training session with a small-step adaptive logic, an apparent lack of improvement could be extremely discouraging to the trainee and therefore impede performance. The addition of augmented feedback depicting actual performance in relation to criterion performance may then help maintain a steady rate of improvement in performance.

Transfer. Although a main effect of training type was significant in transfer with those who received the adaptive training procedure tracking more accurately than those who received the fixed-difficulty procedure, the difference in transfer tracking error was minimal. However, this finding was consistent with the earlier findings of Cote, et al. (1978). As was hypothesized earlier, the reason for superior performance of the adaptive training group in transfer may have been due to the greater amount of practice afforded the adaptive group in keeping the controlled element within tolerance of the forcing function symbol at various levels of difficulty. This, of course, is a basic feature of adaptive training systems.

This result points out an important aspect of adaptive systems that should not be ignored. Adaptive training systems have often been criticized for their development costs, their failure to reduce training time, and their failure to improve training performance. However, if performance in the transfer situation is better than it would be if alternative training procedures were used, then it may be wise to use an adaptive training system. Obviously, many factors would have to be considered in making the decision of what type of a training system to use, but any particular system should not be excluded based on its cost and the training results it produces.

Conclusion

The results of this study suggest that augmented feedback in a closed-loop adaptive training system with clearly discernible intrinsic feedback does not enhance performance in either training or transfer. However, the results obtained may be due to: (1) the limited amount of information that may be provided by augmented feedback in an adaptive system with clearly discernible intrinsic feedback, (2) the feedback not being aversive, (3) the length of the training period, or (4) the features inherent in an adaptive training system. Nevertheless, it appears that augmented feedback will not produce a performance or a learning effect when provided with an adaptive task of short duration that has clearly discernible intrinsic feedback.

Although no effect due to augmented feedback was found in this study, it may be that augmented feedback may aid performance in an adaptive task without clearly discernible intrinsic feedback. One such example would be a compensatory tracking task. In open-loop motor skills research, augmented feedback has been found to produce a performance as well as a learning effect in tasks that lack clearly discernible intrinsic feedback (Von Buseck, 1965; Gibson and Ventola, 1967; and Lintern, 1978). However, in attempting to apply augmented feedback in a closed-lsop system lacking clear intrinsic feedback, one should follow the suggestions that have come out of the numerous open-loop studies that have investigated the effects of augmented feedback.

Thus, if augmented feedback is applied in an adaptive closed-loop system lacking clearly discernible intrinsic feedback, the feedback should: (1) not provide cues which can be relied upon for successful performance throughout training, (2) signal out-of-tolerance performance, and (3) direct the attention of the trainees to the results of their responses and thus their errors. It is hypothesized that if these guidelines are followed in implementing augmented feedback into a closed-loop adaptive motor skill training system lacking clearly discernible intrinsic feedback, a performance as well as a learning effect would be realized. This hypothesis is based on the results of Micheli's (1966) research which suggests that the more information provided by augmented feedback, the greater the effect on performance and learning. However, one must be cautious not to have such poor intrinsic feedback that the trainee relies on the augmented feedback to perform the task. In this situation, a severe performance decrement would occur upon the withdrawal of the feedback.

SUMMARY

A two-dimensional pursuit tracking task was used to teach subjects a complex perceptual motor skill. The primary emphasis of this experiment was to test the effects of off-course augmented feedback on adaptive motor skill learning. Another aim was to examine the combined effects of various augmented feedback types and training procedures.

Previous open-loop motor skill research has shown off-course augmented feedback to produce a learning effect when employed with tasks having clearly discernible intrinsic feedback. It is the general consensus that such feedback, if usable by the trainee, produces a learning effect because: (1) it emphasizes error due to incorrect responses early in training, (2) the supplemental information provided by the augmented feedback is gradually phased out as the trainee becomes more proficient in performing the task such that an abrupt change in information does not occur when the augmented feedback is completely withdrawn, (3) the trainee cannot depend on the off-course augmented feedback to perform the task throughout training, and (4) off-course augmented feedback, if made readily apparent, does not distract from the task being performed as does constant augmented feedback requiring continuous monitoring.

Subjects were taught a two-dimensional pursuit tracking task with a fixed-difficulty training procedure or an automatic adaptive training procedure. Subjects in each training procedure were placed in one of four feedback conditions. The four feedback conditions were:

(1) off-course auditory feedback, (2) off-course visual feedback, (3) off-course auditory and visual feedback, and (4) no augmented feedback. Subjects in the adaptive training procedure who received augmented feedback were also given task difficulty information.

After training to criterion and a 5-min rest period, all subjects were presented with a 6-min no-feedback transfer task identical to the training task. The transfer task consisted of 3 task difficulty levels.

In training, no reliable effect due to feedback or training procedure was found. In transfer, there was no reliable effect due to training feedback. However, the effect of training procedure was significant in transfer with subjects trained adaptively performing significantly better. This effect was anticipated on the basis that adaptively trained subjects receive more practice at various levels of task difficulty during training.

In conclusion, the results of this study suggest that augmented feedback in a closed-loop adaptive training system with clearly discernible intrinsic feedback does not enhance performance. However, it is believed that level of task difficulty information may maintain a steady increase in performance level in adaptive systems requiring training to take place over an extended period. Furthermore, based on the findings of numerous open-loop motor skill studies and the results of this research, it was hypothesized that augmented feedback may produce a performance as well as a learning effect in adaptive systems lacking clearly discernible intrinsic feedback.

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Appendices Omitted

Appendix C

Predicting Optimal Training Group Assignment

PROCEEDINGS of the HUMAN FACTORS SOCIETY-23rd ANNUAL MEETING-1979

PREDICTING OPTIMAL TRAINING GROUP ASSIGNMENT

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ABSTRACT

Multiple regression equations were used to assign 40 students to fixed-difficulty or adaptive training based upon the shorter predicted time-to-train score. In addition, 40 students were randomly assigned to the two training conditions, and 40 students were mismatched to training based upon the longer predicted time to train. Using predicted scores to match students to training alternatives resulted in a 47% savings in training time over random assignment and a 53% savings over mismatched assignment. The assignment effect was reliable at the 0.0001 level. Future research will examine different categories of predictors, additional training alternatives, and more complex training tasks.

INTRODUCTION

The vast storage capacity of the computer has encouraged training designers to provide adaptive instruction tailored to individual student needs. In training, the role of the computer varies from disseminator of information to manager of instruction. As a disseminator of information the computer determines the student's unique trajectory through the curriculum. This is what Hansen (1973) refers to as within task adaption. Hansen defines pretask adaption as the use of the computer as a manager to diagnose and prescribe instruction.

Much research has been directed toward the development of an optimization model to disseminate information. Fletcher (1975) describes four types of quantitative models: memory (e.g., Estes, 1960), artificial intelligence (e.g., Newell, Shaw, and Simon, 1960), automation (e.g., Minsky, 1967), and regression (e.g., Suppes, Fletcher, and Zanotti, 1975). An earlier approach to instructional sequencing, Smallwood's (1962) model, uses both the student's response history as well as the cumulative history of students who took previous courses. In motor skill training the linear adaptive model developed by Kelley (1969) has been the stimulus for a great deal of research. The goal of each of these approaches is to minimize time and instructional costs and to maximize student achievement by adjusting the instructional environment to individual, and perhaps changing, instructional needs.

A second approach to individual differences in training involves the use of the computer as a manager of instruction. Carroll's (1963) learning 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. Bloom (1976) provides three 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 must use a model to determine a priori the appropriateness of a particular training method. For example, regression models might be useful to predict training success. Kaskowitz and Suppes (1978) 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 impetus for the present study 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 instructions) improved prediction. The improvement in prediction when students are grouped by training type suggests that training type interacted with individual differences among students. Perhaps the best score predicted with the various training types could be used to select an optimal training assignment.

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) reports 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 study extended this regression model approach to the perceptual-motor learning domain. Specifically, groups were assigned to various training strategies on the basis of predicted scores from baseline regression models of training time-to-exit. Students were matched (shorter predicted time), mismatched (longer predicted time), or randomly assigned to fixed-difficulty or adaptive training to learn a two-dimensional pursuit tracking task.

METHOD

Regression Equations

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, Oltman, 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 were used to determine equations; those with the fewest predictors and accounting for the most variance were selected.

A double cross-validation procedure was used to validate the regression equations which predicted time to learn a two-dimensional pursuit tracking task. The coefficients of multiple determination were consistently high, so the two samples were combined and new equations generated. The combined sample equations, given in Table 1, were used for training group assignment.

Experimental Design

A 2 x 2 x 3 complete factorial design with two levels of sex, two levels of training (fixed-difficulty, adaptive), and three levels of assignment (matched, random, mismatched) was used. A total of 120 undergraduates were equally divided among the 12 cells of the experiment. All subjects were volunteers and were paid for their participation.

Equipment and Tasks

A PDP 11/55 digital computer provided inputs to a Tektronix 4014-1 cathode ray tube display and processed control inputs from a Measurement System Model 435 isometric control stick.

Each subject completed a series of trials to learn a two-dimensional tracking task in which random functions were used to determine the x-y coordinates of the forcing function symbol (X).

Table 1

Combined Sample Regression Equations for Training Time-to-Exit

---

Adaptive Training

$TE = 1326.85 + 381.82\ EF - 307.48\ MM + 259.52\ SE$

$n = 51$
$R^2 = .756$
$R_s^2 = .740$
$p \leq = .0001$

Fixed-Difficulty Training

$TE = 995.57 + 405.77\ EF + 271.30\ IP - 139.28\ CC$

$n = 48$
$R^2 = .632$
$R_s^2 = .607$
$p \leq = .0001$

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

The control output (0) was generated using inputs from the analog controller. Dynamic, augmented visual feedback in terms of tracking error and task difficulty was provided. Task difficulty was manipulated in terms of the movement speed and distance of the forcing function symbol. Exit criterion was obtained when the student maintained exit criterion task difficulty and acceptable accuracy for a period of 20 seconds.

Two training conditions were available--fixed-difficulty and adaptive. In fixed-difficulty training the criterion level of task difficulty is presented throughout training, and student error decreases over time. Adaptive training (Kelley, 1969) is a closed-loop system in which task difficulty varies during training as a function of student performance.

Following training and a short rest period, each subject completed a 7-minute transfer task in which no augmented feedback was provided. Task difficulty changed automatically after each minute of tracking. Three levels of difficulty were used: the same as exit criterion in training, more difficult than exit criterion, and less difficult than exit criterion.

RESULTS AND DISCUSSION

Training Time

The correlation between predicted and actual time-to-exit scores was .757. For only the students receiving adaptive training the correlation was .789; for fixed-difficulty training it was .716. Coefficients of multiple determination were somewhat lower than the estimates of shrinkage (R_s^2) given in Table 1.

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, $F(1,108)=40.57$, $p<.0001$. Matched subjects required significantly less time to exit than either random or mismatched subjects, and males required significantly less training than females. There was no reliable difference between training alternatives ($p=.246$).

Use of the regression equations to predict optimal training type resulted in savings of 47% of training time over random assignment and 53% over mismatched assignment. Variance in training time was reduced approximately 40% by optimizing training group assignment. Table 2 summarizes the reliable effects from the analysis of training time.

These data strongly support the use of regression equations to optimize training group assignment. The optimization procedure resulted in savings in training time and a reduction in variance among students. Interestingly, no overall difference in training time between fixed-difficulty and adaptive training was noted. If the study had employed only random assignment, one might have erroneously concluded that no advantage is to be gained in providing alternative training conditions.

Transfer Task Accuracy

An analysis of variance on vector root mean square tracking error in the transfer task revealed a reliable main effect of level of difficulty $F(2,216)=386.2$, $p<.0001$, indicating that the three levels of tracking difficulty did represent different skill levels for the students.

The performance differences between males and females also appeared in transfer with males performing more accurately than females, $F(1,108)=14.53$, $p=.0002$. In addition, there was a reliable interaction between level of difficulty and sex, $F(2,216)=5.30$, $p=.00057$. Although all post hoc comparisons were reliable ($p<.05$), the superiority of males over females was most pronounced at the highest level of task difficulty.

The main effect of assignment was again reliable in transfer, $F(2,108) = 7.98$, $p=.0006$. Post hoc analyses confirm that the reliable differences in transfer were between random and mismatched assignment and between matched and mismatched assignment. It is important to point out that the assignment optimization procedure was based on training time, not transfer performance. Therefore, marked differences in transfer were not expected since students were trained to the same exit criterion.

Table 2

Summary Statistics for Training Time-to-Exit (min)

Effect	$\bar{X}$	σ
Training Type		
Adaptive	17.5	12.4
Fixed-Difficulty	15.6	10.1
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

CONCLUSIONS

These data clearly support the notion that training can be improved by providing alternative training procedures with assignment based upon an optimization model. In addition, the research supports the efficacy of a regression approach for assignment optimization.

To facilitate implementation in operational training systems, research is warranted to examine regression optimization with additional types of predictors, training procedures, and more complex training tasks. Guidelines for selection of viable predictors is particularly critical. The experience with the Advanced Instructional System vividly portrays the complexity of implementing innovative training programs. However, if the computer is ever to provide real value to training systems, the challenge of the operational training system must be conquered.

ACKNOWLEDGMENTS

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Appendix D

Prediction of Performance in Motor Skills Training

AD-A083 781   VIRGINIA POLYTECHNIC INST AND STATE UNIV BLACKSBURG --ETC F/G 5/9
AUTOMATED MOTOR SKILLS TRAINING OPTIMIZED FOR INDIVIDUAL DIFFER--ETC(U)
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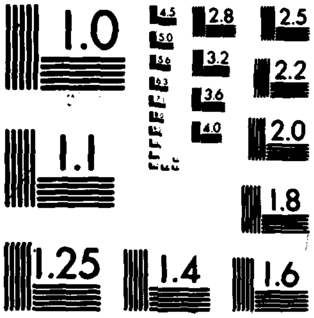

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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PREDICTION OF PERFORMANCE IN MOTOR SKILLS TRAINING

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ABSTRACT

Williges, Williges, and Savage (1979) demonstrated the utility of a multiple-regression approach for assigning individuals to training alternatives. Average training time savings of 50% were obtained when the lower predicted score was used to assign students to fixed-difficulty or adaptive training conditions to learn a two-dimensional tracking task. The present study extends this work by developing prediction models for a real-world training task. Regression models were developed to predict performance on several flight manuevers using the ATC-610 Flight Trainer. One hundred VPI undergraduates and 100 USAF cadets, with an equal number of males and females, served as subjects.

The predictors included measures of information processing skills, motor skills, and demographic characteristics. The measures of information processing skills were: (1) Embedded Figures Test (field independence); (2) Identical Pictures Test (perceptual speed); (3) Maze Tracing Test (spatial scanning); (4) Map Memory Test (visual memory); and (5) Cube Comparisons Test (spatial orientation). The motor skills tests were the Psychomotor Test Device Tests 1 and 2 (Systems Research Laboratories) and the pursuit rotor. Demographic predictors included sex and educational institution. Differences in reliable predictors for males versus females, cadets versus undergraduates, and tracking versus flight trainer performances are discussed.

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The goal of this programmatic research effort was to investigate the ramifications of both micromodels and macromodels in individualizing motor skills training. Specifically, the research conducted during 1 October 1978 to 30 September 1979 dealt with the use of feedback in adaptive training, the extensions of regression approaches to training group assignment, and the evaluation of population differences.

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