A COMPARISON OF COMPUTER-AIDED TRAINING VERSUS CONVENTIONAL METHODS

DR. RONALD E. OFFENSTEIN, MR. G. DONALD LODIN, AND DR. GLENN D. BUELL

Autonetics Marine Systems Division
Electronic Systems Group
Anaheim, California 92803

The capability of the digital computer has been examined by training equipment designers for several years with the hope of improving the speed and/or quality of instruction. The general term, computer-aided instruction (CAI), has emerged to describe the use of a computer to prompt, provide feedback, adjust task difficulty, or enable flexible sequencing for learners and/or training facilities. The use of a computer in these roles is generally assumed to improve instruction, and possibly reduce recurring costs by lowering instructional personnel requirements. However, research comparing traditional instruction with CAI is somewhat limited in terms of generalization making verification of this assumption for a particular training situation difficult. The study reported here is intended to extend understanding of the use of CAI to the depth control task of a remotely controlled submersible vehicle (RCSV).

Of the many potential computer applications to the problem of learning to control depth of a RCSV, two were selected. First, an adaptive algorithm was constructed to adjust the level of difficulty that an operator experienced while learning the control task. Second, the level of disturbance was shown numerically to the operator, thereby providing feedback about his performance. Thus, the computer was used to vary the task difficulty in accordance with an operator's performance and provide feedback to the operator about his performance.

Two approaches to varying task difficulty were considered at the outset of this study although only one was tested. The first approach considered would have operated on the vehicle or control system dynamics to lower the difficulty of control for beginners. An algorithm modifying the task difficulty by this technique would be based on a response variable, and should be distinguished from stimulus variable modifications. In contrast, this latter technique adjusts task difficulty by varying a disturbing force.

A vehicle such as a RCSV is designed to be stable unless disturbed by a force; some disturbing forces arise from an operator's control commands while others result from changes in water temperature, salinity, or current. Experienced control operators minimize the amount of self-induced disturbance but beginners often inject a good deal of disturbance which, when mixed with environmental disturbance, is experienced as an overwhelming control task. The use of an adaptive model to add or subtract environmental disturbance in accordance with an operator's performance may aid beginners in distinguishing their own disturbance from that of environmental sources and, therefore, enable them to learn more clearly the effects of their control commands. This approach to an adaptive model was selected for the study reported here.

In brief, this study examined the effects of CAI on a beginner's performance in learning to control RCSV depth. Two groups of subjects were involved; one group attempted to learn the control task with the CAI model while the other group had the same amount of practice but under constantly difficult conditions. The performance of the groups was compared for training and transfer trials in order to assess the merit of CAI as applied to this particular task.

METHOD

Subjects

From a pool consisting of clerical and engineering personnel, 18 volunteer test subjects were selected on the basis of availability during the data collection period; the group was composed of three females and 15 males.

Some of the test subjects were experienced in the control of aircraft and/or ships; this experience varied considerably from one hour in a simulator to several years as senior operational personnel. Fifteen of the subjects had no prior experience directly related to the experimental task.

Experimental Setting

A modular, reconfigurable control station was used as the operator's station. This station, shown in Figure 1, presented stern plane position, depth rate, ship's angle, depth error, speed, depth, and problem difficulty level to the subject (other displays were present but inactive during the experiment as they did not pertain to the task of depth control). The subject controlled the stern planes with a hand lever that when pushed forward caused the planes to go into a dive position and when pulled back caused the planes to rise.

The control station was interfaced with a digital computer which was programmed with the equations of motion for the simulated vehicle. This computer also contained the adaptive algorithm, data recording software, disturbance model, and additional programs needed for the real-time simulation. A test conductor's station, shown in Figure 2, was used to control the simulation and data recording. The controlled vehicle was a miniature, remotely controlled submersible approximately 30-feet long with only stern planes for pitch/depth control.

Adaptive Algorithm and Disturbance Model

Ten levels of difficulty were selectable by the adaptive algorithm or the test conductor. A subject using the CAI condition experienced an increase in difficulty every 90 seconds providing depth error did not exceed 10 feet at any time during the 90 seconds. If a depth excursion larger than 10 feet occurred, the difficulty was decreased one level; if control was regained and maintained for 30 seconds, the difficulty was increased to the prior level. Successive depth excursions greater than 10 feet resulted in one level decrements until the subject was back to the starting level.

The disturbance model was constructed from six sine waves of different frequencies. The frequencies were selected so that they would not be higher than the response of the RCSV nor lower than would permit one complete cycle within the training trial-time period. The sum of these sine waves was multiplied by a gain and the level of difficulty (1-10). The disturbance force was applied through the center-of-gravity of the RCSV causing a vertical acceleration which appeared to the operator as a disturbance to the depth of the vehicle.

Experimental Design, Procedure, and Performance Measures

A split-plot design was used for this study. This is a factorial design with block-treatment confounding; in the study described herein, the between-block or nonrepeated measures variable was the training technique (CAI vs Fixed difficulty) while the within block or repeated measures variable was the transfer task (three difficulty levels: low, medium, high; and a depth changing maneuver). The complexities and limitations of this design were warranted by the availability of subjects and the nature of the experimental treatments; moreover, tests for homogeneity of pooled variances indicated the acceptability of this technique.

As indicated by the above design, two basic subject groups were obtained by random sampling from the volunteer pool. One group, designated the CAI group, began each training trial with a difficulty level of 1 and progressed as determined by the adaptive model up to a level of 5. Progress within each training trial was determined by the subject's performance; it was possible for a subject to spend most of the trial at level 1, level 5, or any level or combination of levels in between. The other group, designated the Fixed group, began each training trial at a difficulty level of 5; this difficulty level was not varied during any of the training trials.

Each group had three 10-minute training trials separated by approximately 1 minute of rest. At the end of the three training trials, both groups were given a series of four transfer trials. The first three of these trials required the subject to maintain a depth; each of these three had a different difficulty level associated with it (low=1, medium=5, high=10). The fourth transfer trial required the subjects to execute a 100-foot depth change. At the conclusion of the fourth transfer trial, the subject had completed the experiment.

All subjects received a welcoming and explanatory letter outlining the basic goals of the study; when a subject arrived at the simulation facility, he/she was taken to the test station and read the following instructions:

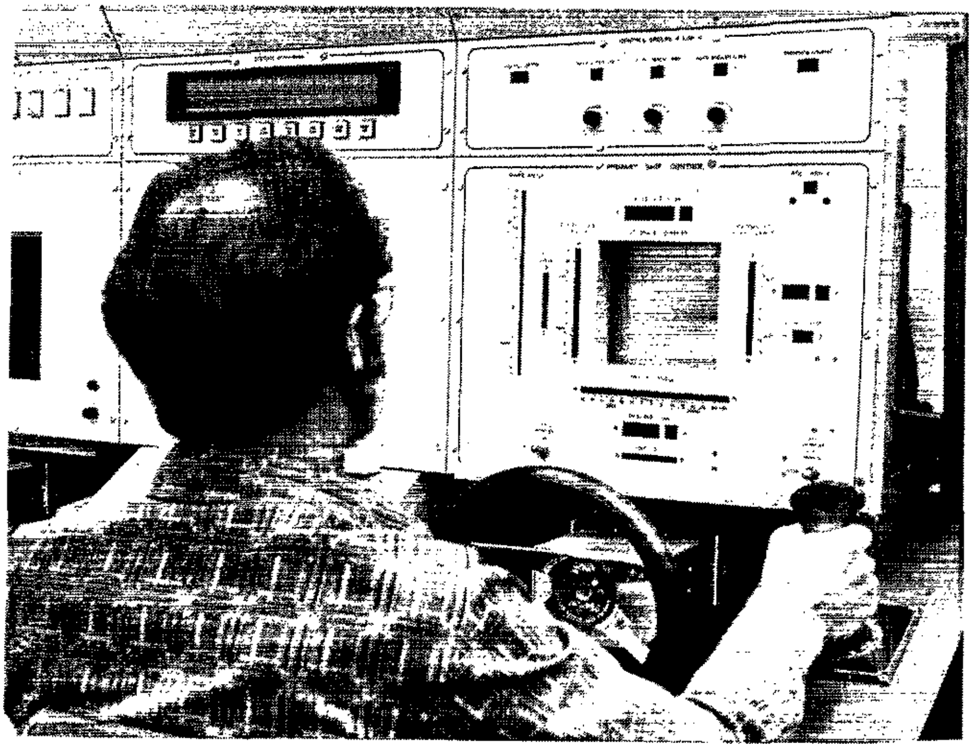


Figure 1. Operator's Control Station

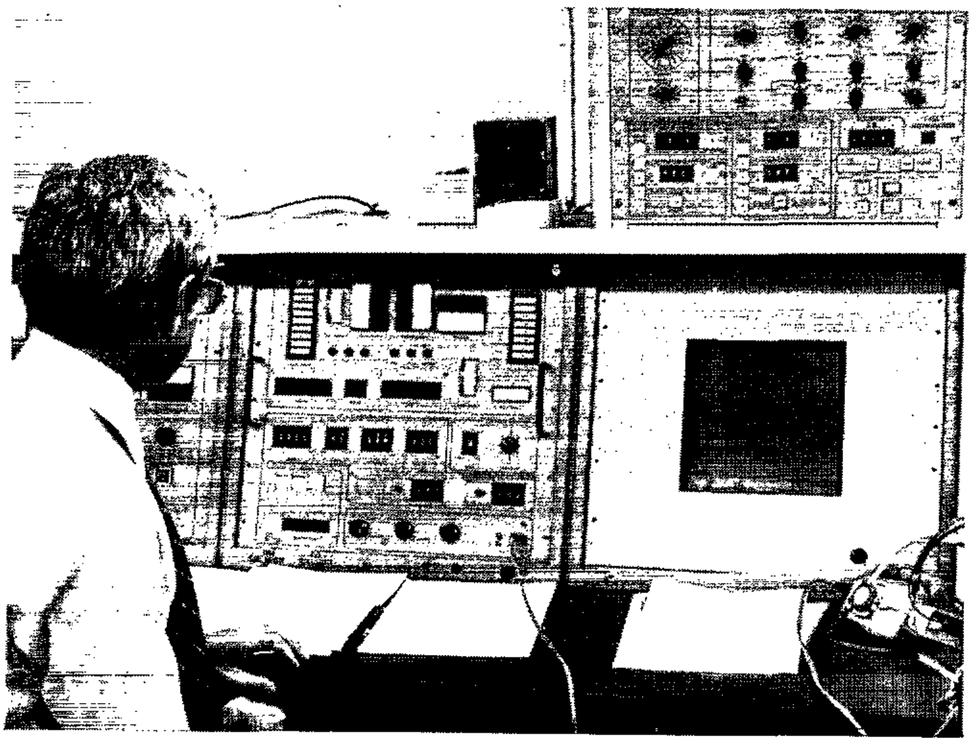


Figure 2. Test Conductor's Station

WELCOME:

You have been asked to participate in a study intended to investigate the utility of various submersible control training techniques. The task you will be trying to learn involves remotely controlling the sternplanes of the submersible vehicle to maintain or change depth. The planes are controlled by this (point) control lever; pulling back on the lever causes the planes to go up as shown by this indicator (point). When the planes go up, the front of the submersible will go up as shown here (point) and depth will decrease as indicated by the depth gage (point). The reverse of all this happens when the control lever is pushed forward. In short, pull the lever back to go up, push the lever forward to go down.

In addition to the indicators that I have already shown, the CRT directly in front of you shows depth error; when the cross is within the box, depth error is within an acceptable limit. Your task will be to keep depth at 300 feet.

Although ship's course can be controlled from this station, it does not pertain to the present investigation and should be ignored. Let me briefly describe the remaining indicators in front of you. (Point and explain.)

Do you have questions?

It is time for you to try controlling the submersible. To get started, push these buttons when I indicate (depth and course entry). We will need to talk over this head set as I will be up there (point). Let's get started.

If a subject had exceptional difficulty becoming oriented to the task, a modest effort was made to get him/her started; this was done for both groups and never exceeded a few orienting comments within a 2-3 minute period. With the exception of these efforts, all subjects were on their own to learn the task of depth control.

Performance measures consisted of RCSV responses, operator control commands, and the task difficulty level as determined by the adaptive model (pertains only to CAI group during the training trials). A listing of all performance measures is given in Table 1.

TABLE 1. PERFORMANCE MEASURES

1. RMS depth error
2. Integrated absolute depth error
3. Proportion of time within ± 1-foot depth band
4. Frequency of sign reversals in hand controller position
5. Performance index (mean quadratic combination of depth error and plane position)
6. Mean absolute plane rate
7. Percent time planes saturated (displaced to maximum position)
8. Mean absolute hand controller displacement.

Training Trials

Both CAI and FIXED groups were given three successive 10-minute training trials. Recalling that task difficulty for the CAI group was determined by ability to control the RCSV depth, it would be expected that the average task difficulty would increase as training progressed. Figure 3 shows that this did occur; however, it is interesting to note that after 30 minutes of training the average difficulty level had reached only 3.8; the FIXED group experienced a constant difficulty level of 5 throughout the training trials.

It is difficult to directly compare the performance of the separate groups during training because they were not working at the same level of difficulty. The question of whether the FIXED group was learning can be answered only indirectly by examining the change in selected performance measures as shown in Table 2. These data generally reflect modest performance improvements over the three training trials.

TABLE 2. SELECTED PERFORMANCE MEASURES FOR THE FIXED GROUP OVER THE THREE TRAINING TRIALS

	Trial 1		Trial 2		Trial 3	
	mean	SD	mean	SD	mean	SD
RMS depth error	16.05	10.05	12.80	16.90	9.90	6.00
Frequency of sign reversals in hand control position	.26	.11	.27	.13	.25	.15
Performance index	18.50	8.00	17.20	9.26	16.20	10.50
Average absolute plane rate	6.78	3.40	6.70	3.80	6.60	4.00
% time planes saturated	9.70	16.20	5.80	13.00	8.00	13.00

Transfer Trials

Three transfer trials followed the training trials for both groups; to the extent that operators had learned to control the depth of the RCSV during the training trials, performance on the transfer trials should have been improved. If the CAI method of instruction facilitated learning in comparison with the FIXED technique, it would be expected that CAI group performance would be better than that of the FIXED group.

The other main effect examined in this study was the level of difficulty of the transfer task. As it turned out, this variable accounted for more variance and had a more reliable effect than did the method of instruction: Analysis of Variance (ANOVA) summary tables for RMS depth error, proportion of time within a ±1-foot depth band, the performance index, and average absolute hand controller deflection are shown in Figure 4.

Although the method of instruction did not turn out to be a statistically powerful variable, the general trend in much of the data indicated that the assumed benefits of CAI may have been realized. This is reflected by Figure 5 in which values of the above variables are plotted for the three transfer trial levels of difficulty. In the cases shown, the CAI group seems to maintain better RCSV control in that RMS error is lower for difficulty levels one and two, a greater proportion of time was spent in a ±1-foot depth band, and the performance index is lower. This group also had slightly less average absolute hand controller deflection, a measure indicating that the task should have been less fatiguing. Two of the observed differences between the CAI and FIXED groups are significantly different ($P < .10$)*; in most cases the differences between the low and intermediate difficulty levels are significant ($P < .05$) for both groups.

The final transfer trial required operators of both groups to execute a 100-foot depth change maneuver. The purpose in doing this was to examine the transfer effects of both methods of instruction to a task not specifically encountered during training. The performance of both groups was essentially equivalent on this task. Average transition duration for the CAI group was 100 seconds while that of the FIXED group was 106 seconds.

DISCUSSION

CAI as a method of teaching remotely controlled submersible vehicle (RCSV) depth control was compared with a FIXED difficulty technique. The CAI group experienced three training trials during which their performance determined the level of task difficulty; the FIXED group had an equal amount of training but their experience was always at a constant (intermediate) difficulty. It was anticipated that the CAI group would learn depth control more rapidly because the amount of disturbance to the depth of the submarine was adjusted in accordance with their performance,

*In concluding that a reliable difference exists between the CAI and FIXED group, there is less than a .10 probability of being incorrect.

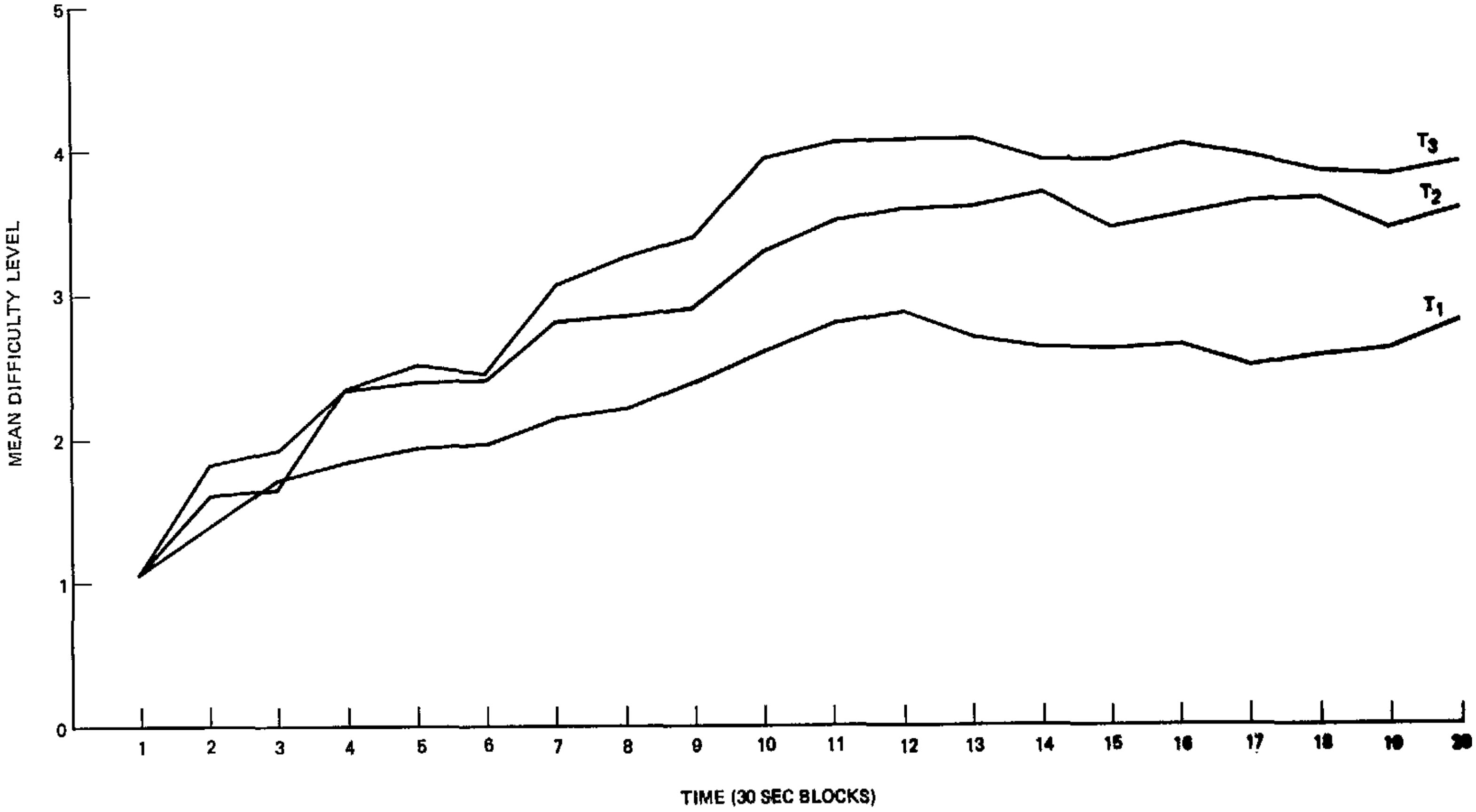


Figure 3. Mean Difficulty Level for CAI Group for the Three Training Trials

RMS DEPTH ERROR

Source	df	MS	F
1. Between subjects			
a. A (type of training)	1	29.43	.3049
b. Sub w·group	16	96.50	
2. Within subjects			
a. B (transfer task difficulty)	2	230.82	6.71**
b. AB	2	56.10	1.63
c. B x sub w·group	32	34.38	

Proportion of time within ± 1 foot of depth

Source	df	MS	F
1. Between subjects			
a. A (type of training)	1	.1116	3.455*
b. Sub w·group	16	.0323	
2. With subjects			
a. B (transfer task difficulty)	2	.428	36.87**
b. AB	2	.0553	4.77**
c. B x sub w·group	32	.0116	

Performance Index

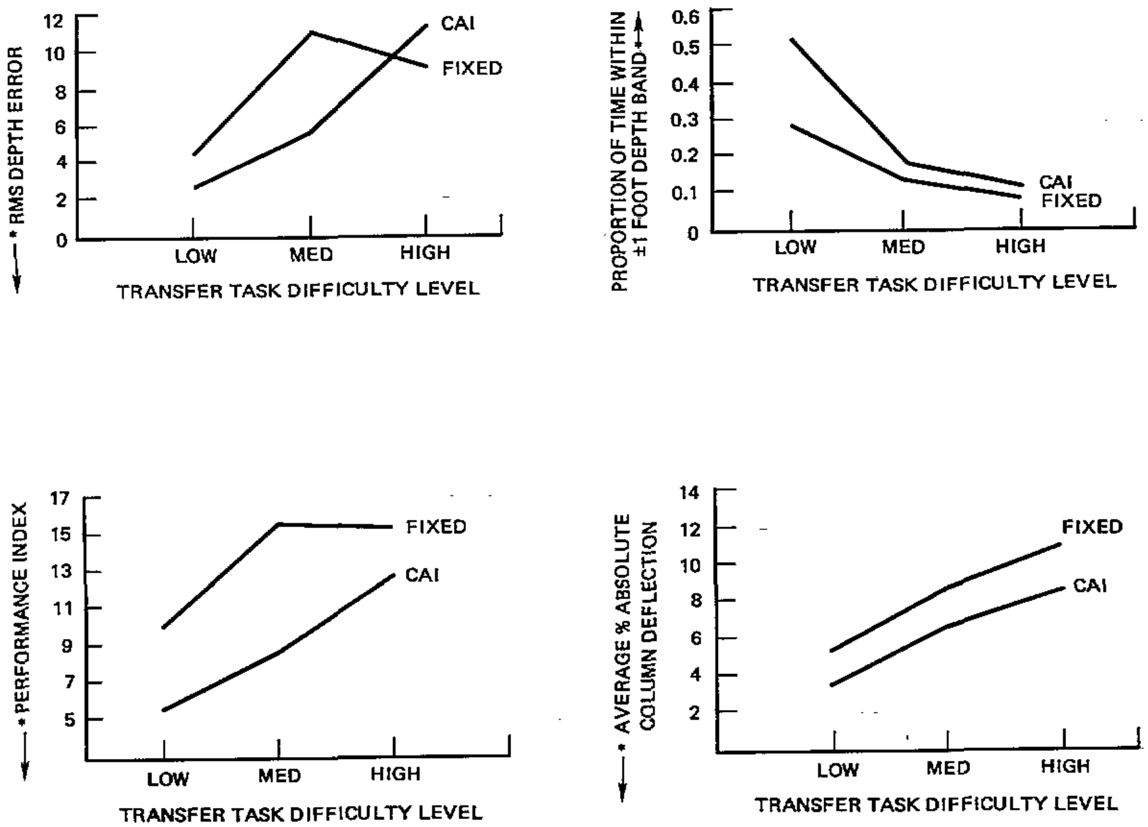
Source	df	MS	F
1. Between subjects			
a. A (type of training)	1	268.39	3.41*
b. Sub w·group	16	78.55	
2. Within subjects			
a. B (transfer task difficulty)	2	179.03	26.21**
b. AB	2	19.85	2.906
c. B x sub w·group	32	6.83	

Average Absolute Hand Controller Deflection

Source	df	MS	F
1. Between subjects			
a. A (type of training)	1	53.78	1.33
b. Sub w·group	16	40.289	
2. Within subjects			
a. B (transfer task difficulty)	2	126.44	76.71**
b. AB	2	.08	.05
c. B x sub w·group	32	1.65	

* $P < .10$ ** $P < .05$

Figure 4. ANOVA Summary Tables for Four Variables



*Arrow indicates direction of performance improvement.

Figure 5. Mean Performance Measure Values for the CAI and FIXED Groups Across the Three Transfer Trials

thus permitting a clearer separation between the effects of their control commands (operator induced disturbance) and environmental disturbances. Although the trend in many of the performance measures was in support of this hypothesis, statistically reliable results were not obtained for all performance measures.

An examination of the performance of individuals within the CAI group revealed considerable variance. Some operators never progressed beyond difficulty level 1 during the thirty minutes of training while others advanced steadily. It seems reasonable that this wide variation in entering behavior is primarily responsible for the lack of statistically strong CAI effects.

Two aspects of the large ability differences obtained in this study appear to be of interest. First, an appropriate CAI system must either be designed with the level of entering ability in mind or it must be able to compensate for these differences. In the case of depth control, a CAI system would have needed to adjust response variables (i.e., RCSV dynamics) in order to lower the difficulty to an appropriate level for the operators participating in this study. Second, statistical reliability could most likely be obtained in a study like the one reported here by increasing the number of subjects; in effect, increasing the number of subjects tends to diminish the importance of the few operators who appear to be unable to establish control over the RCSV. However, this approach is not economically practical in an industrial research setting. Instead, experimental designs that permit a maximum of understanding with a minimum of subjects and time are dictated by the costs of test personnel and facilities.

CAI is most likely going to be an increasingly prominent part of modern instructional systems. Its success depends upon a thorough understanding of the many variables involved in a particular instructional setting, making generalizations difficult. In the case of RCSV depth control, this study has shown that the range of entering ability must either be constrained or the CAI system must be capable of a broader range of difficulty levels. More extensive training time may improve the picture of CAI presented in this study; but an approach that fails to reduce entry level complexity would not reduce the learner's intense frustration resulting from very limited performance improvements during the initial training periods.

ABOUT THE AUTHORS

DR. RONALD E. OFFENSTEIN is an Autonetics Marine Systems Division Consultant in Human Engineering and experimental design at Rockwell International. He is responsible for part-task and full-station real-time man-in-the-loop simulation studies. He also participated in the design of advanced control station concepts for various submarine and surface ship applications. At McDonnell-Douglas Astronautics, he was responsible for course preparation and presentation on propulsion and guidance systems, conducted simulated zero-gravity tests to verify operational procedures, and prepared task analyses for selected mission operations. In 1969, he joined Autonetics as a member of the Technical Staff, working on the F-111 Training Program, and experimental evaluation of plane and rudder quickened commands for SSN 688. He was Assistant Professor of Psychology at San Bernadino Valley College. Dr. Offenstein holds B.A. and M.A. degrees in psychology from California State College and a Ph.D. in psychology from Claremont Graduate School.

MR. G. DONALD LODIN is Manager of Control Systems Engineering at Rockwell International. He is responsible for planning and direction of engineering and preliminary design of shipboard control systems. His activities include: Proposals, independent R&D tasks, and contract work related to submarine control systems, surface ship bridge and propulsion controls, and ship collision-avoidance systems. He formerly worked on the development of the flight control system for the Minuteman ICBM. As a senior research engineer, he was responsible for R&D of spacecraft and missile attitude-control systems. He was Chief of Guidance and Control, Ocean Systems Operations responsible for planning and directing engineering activities related to the guidance and control of a broad range of ocean-based systems. He was also a member of Marine Systems Division Technical staff responsible for submarine control system research. He holds a B.S.A.E. degree from Massachusetts Institute of Technology.

DR. GLENN D. BUELL, JR. is Manager of Command Control Systems at Autonetics Marine Systems Division at Rockwell International. He directs electronic design, control systems analysis, human factors engineering, and real-time simulation. He has performed analysis on various navigation systems, developed a polar mode reset mechanization for SSN applications, and served as engineer for ship Dynamics and Control, Dynamics Unit, and Manager for all Marine Systems Division's Washington, D.C. engineering activities. From 1956 to 1957 and from 1962 to 1969, he participated in design, analysis and test of control systems for missiles, aircraft, and atmospheric reentry vehicles. As an Air Force pilot from 1957 to 1962, he logged more than 2,000 hours flight time in B-47, C-45, C-119, KC-135, T-28, T-33, and T-34 types of aircraft. He holds a B.S. degree in aeronautical engineering from Texas A&M, the M.S. in mechanical engineering from University of Southern California, and a Ph.D. in electrical engineering from the University of California at Los Angeles.