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ACQUISITION OF A PSYCHOMOTOR SKILL USING SIMULATED-TASK, AUGMENTED FEEDBACK (EVALUATION OF A WELDING TRAINING SIMULATOR)

Macy L. Abrams, et al

Navy Personnel Research and Development Center
San Diego, California

October 1974

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

The present investigation evaluates the effectiveness of simulated-task, augmented feedback on acquiring a physically complex, continuous three-dimensional psychomotor skill. Since the device designed to provide the feedback was an arc-welding training simulator, the study also evaluates its training effectiveness. Data from the study support the hypothesis that simulated-task, augmented feedback is significantly superior to that provided by the task itself.

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(Evaluation of a Welding Training Simulator)

Macy L. Abrams
Harvey B. Schow
James A. Riedel

Reviewed by

Edward J. Pickering

Approved by

James J. Regan
Technical Director

Navy Personnel Research and Development Center
San Diego, California 92152

FOREWORD

This research was performed under Exploratory Development Task Area PF55.522.004 (Exploring New Technologies for Designing Navy Training Courses) and Work Unit Number PF55.522.004.01.58 (Innovative Uses of Feedback to Maximize the Transfer of Perceptual and Perceptual-Motor Training). The research was initiated in response to requests from the Chief of Naval Technical Training and the Service School Command, San Diego, to develop improved training methods for welders. Earlier efforts toward this end can be found in: (1) NPTRL SRR 72-61, Development and Evaluation of Experimental Arc Welding Training Procedures and Techniques by M. L. Abrams and M. N. Carr, September 1971 and (2) NPTRL SRR 73-23, Description and Preliminary Training Evaluation of an Arc Welding Simulator, by M. L. Abrams, W. R. Safarjan, and R. G. Wells, June 1973.

Appreciation is expressed to LCDR Ronald W. Myers, Director, Class "C" Welding School, San Diego, and to CWO 3 Benjamin F. Burns, Director, Phase 2 HT Class "A" School, San Diego, and their respective staffs for their support and cooperation. Special acknowledgement is extended to ETCS Kenneth L. Davidson, NPRDC, and personnel from the Class "C" Welding School who manufactured the prototype simulators.

J. J. CLARKIN
Commanding Officer

SUMMARY

Problem

This research was conducted to determine if a physically complex, continuous, three-dimensional psychomotor skill (such as silver brazing, welding, precision soldering, or fusing and defusing ordnance) could be acquired more efficiently with simulated-task, augmented feedback than with the feedback normally provided by performing the task itself. The specific skill selected for this study was arc welding because it is representative of this class of skills and, in addition, it represented a skill area where Navy training problems exist. In order to test the hypothesis, an arc welding training simulator was developed. Consequently, this study also evaluates the training effectiveness of the simulator.

Background and Requirements

Research into the effects of feedback on learning has been extensive but generally focused on summary feedback in verbal learning. Most research on psychomotor skills has been concerned with the effects of applying augmented feedback on physically simple tasks with varying degrees of cognitive complexity such as simple positional or rotary-pursuit tracking. Such research has not dealt with simulated-task, augmented feedback, and differing conclusions relative to task-oriented, augmented feedback have been reported.

With reference to complex psychomotor skills, simulators have been used primarily to consolidate and maintain skill rather than provide initial skill learning, even though evidence suggests they can be successfully employed in the latter case. In addition, simulator research has generally been conducted in areas where (1) high costs limit the use of the actual equipment in training and (2) highly complex equipment requires involved training programs.

Approach

To provide the desired simulated-task, augmented feedback, a device was built consisting of (1) a motor-driven unit representing a welding electrode holder (stinger) and electrode (rod), (2) a moving target representing the welding path, and (3) a box housing digital recorders and error sensors for use to provide immediate operator feedback. The welding skill monitored by the sensors were length of arc, manipulation of the molten puddle (tracking), and angle of electrode.

Thirty-six inexperienced welding trainees were selected from the enrollment in the Hull Technician (HT) "A" School, San Diego, between 20 September and 15 November 1973. Eighteen students were assigned to an experimental group and alternated their time equally between the simulator and the weld shop. The remaining 18 trainees were assigned to the control group and received conventional welding practice only. After about 12 days of training, their performance, by visual grading of the vertical and overhead test plates, was evaluated.

Conclusions and Recommendations

1. The simulator trainees performed significantly better than the conventionally trained group. Therefore, it appears that: (1) it is possible to acquire a physically complex continuous three-dimensional psychomotor skill more efficiently with simulated-task, augmented feedback than with the feedback provided by performing the task itself, and (2) the prototype device used in this study can be utilized effectively to train arc welders.

2. The simulator trainees used 215 times less electrical energy, substantially less welding materials, and spent approximately half as much time in the weld shop. Thus, it appears that widespread use of the device would provide substantial savings and increased training capabilities, e.g., the number of welders being trained at any given time could be greatly increased by rotating blocks of trainees between simulator and weld shop practice. The device could be used: (1) to assist in maintenance of skills where actual welding practice is not possible, such as during submarine patrols, (2) to select men with the greatest potential for success in welding school, and (3) as a research vehicle to study other physically complex psychomotor skills (e.g., silver brazing or precision soldering).

3. The prototype simulator should be refined prior to recommending wide-scale usage in the Fleet. If it is to be used aboard ship, it should be engineered to be made compatible with the shipboard environment (e.g., ruggedized and developed in accordance with applicable military specifications).

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ACQUISITION OF A PSYCHOMOTOR SKILL USING
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Introduction

Problem

The purpose of this research was to determine if a physically complex, continuous, three-dimensional psychomotor skill (such as silver brazing, welding, precision soldering, or fusing and defusing ordnance) could be acquired more efficiently with simulated-task, augmented feedback than with the feedback normally provided by performing the task itself. The specific skill selected was shielded metal arc welding because it is representative of this class of skills and is an area where Navy training problems exist. To test the hypothesis, an arc welding training simulator was developed. Consequently, this study also evaluates the training effectiveness of the simulator.

Background

Research into the effects of feedback on learning has been extensive but generally focused on summary feedback in verbal learning (e.g., Wexley & Thornton, 1972). Most research on psychomotor skills has been concerned with the effects of applying augmented feedback on physically simple tasks with varying degrees of cognitive complexity. Included are such skills as (1) simple positional or rotary-pursuit tracking (e.g., Bilodeau and Rosenquist (1964); Blaiwes (1970); Blaiwes and Regan (1970); Briggs (1962a and 1962b); Gordon and Gottlieb (1967); and Williams and Briggs (1962)), (2) control-stick manipulation on aircraft simulators (e.g., Briggs and Wiener (1959); Briggs (1961); Naylor, Briggs, and Buckhout (1963); and Regan (1959)), and (3) visual tracking on gunnery simulators (e.g., Goldstein & Rittenhouse (1954)).

In this research, differing findings have been reported. For example, in tracking studies, Bilodeau and Rosenquist (1964) found that rotary-pursuit performance was not sensitive to supplementary feedback; Briggs (1962a) found that it was best to use augmented feedback when the subject was in error; and Karlin (1965) found that it was advantageous to use augmented feedback when the subject was on-target. Blaiwes and Regan (1970) concluded that: (1) it was difficult to generalize psychological findings across the different skilled perceptual motor performance tasks, and (2) there is little persuasive evidence demonstrating relationships between motor tasks characteristics and learning variables.

In a continuous task like welding, augmented feedback may also be termed cuing. Briggs (1962a) defined augmented feedback as information provided to the human operator in a skill task which is supplementary to the feedback inherent in the operation of the task itself. In addition, the distinguishing characteristics of augmented feedback are that it represents an evaluation of operator system performance and occurs with minimal lag. Smode (1962) defined augmented feedback as extra-performance cues or information to the operator that indicate when his performance is within specified accuracy limits. Annett and Clarkson (1964) and Annett & Paterson (1966 & 1967) defined cuing as the provision of stimulus information before or during a response such that the response is made more effective or more likely to occur than would be the case without such information. In the present research, the training simulator provides immediate feedback when the subject exceeds defined parameters. The augmented feedback following a response thus becomes stimulus information for the continuing response and can be called either cuing or feedback.

Simulator research conducted thus far has been stimulated by: (1) the rising capital and operating costs of military and industrial equipment which prohibit its use in training, and (2) the increasing equipment complexity which demands involved training programs (Hammerton, 1966). In complex psychomotor skill training, simulators have been primarily used to consolidate and maintain skills rather than provide initial skill learning. For example, pilots gain their skill initially in training aircraft, but maintain this skill by practicing in simulators (Gagne, 1962).

Description of the Task

Shielded metal arc welding consists of (1) joining two or more metals together by melting them with an electric arc, (2) mixing them while they are in a liquid state, and (3) allowing them to return to a solid state. The arc is generated by a consumable metal electrode, which becomes part of the finished weld. To perform the task, the welder moves in different dimensions, depending on the welding position. For example, in the overhead position shown in Figure 1, the welder simultaneously moves as follows:

1. He rotates his wrist axially, causing the tip of the electrode to move sideways--about 1/4 inch (between A and B in Figure 1) and slightly forward--about 1/32 inch, while pulling his arm toward his body along the weld path. This movement requires distinct pauses at the end of each limit[1].

[1] Other equally complex motions can be combined to produce a weld. The choice of the fundamental motion described was influenced by expert welder opinion.

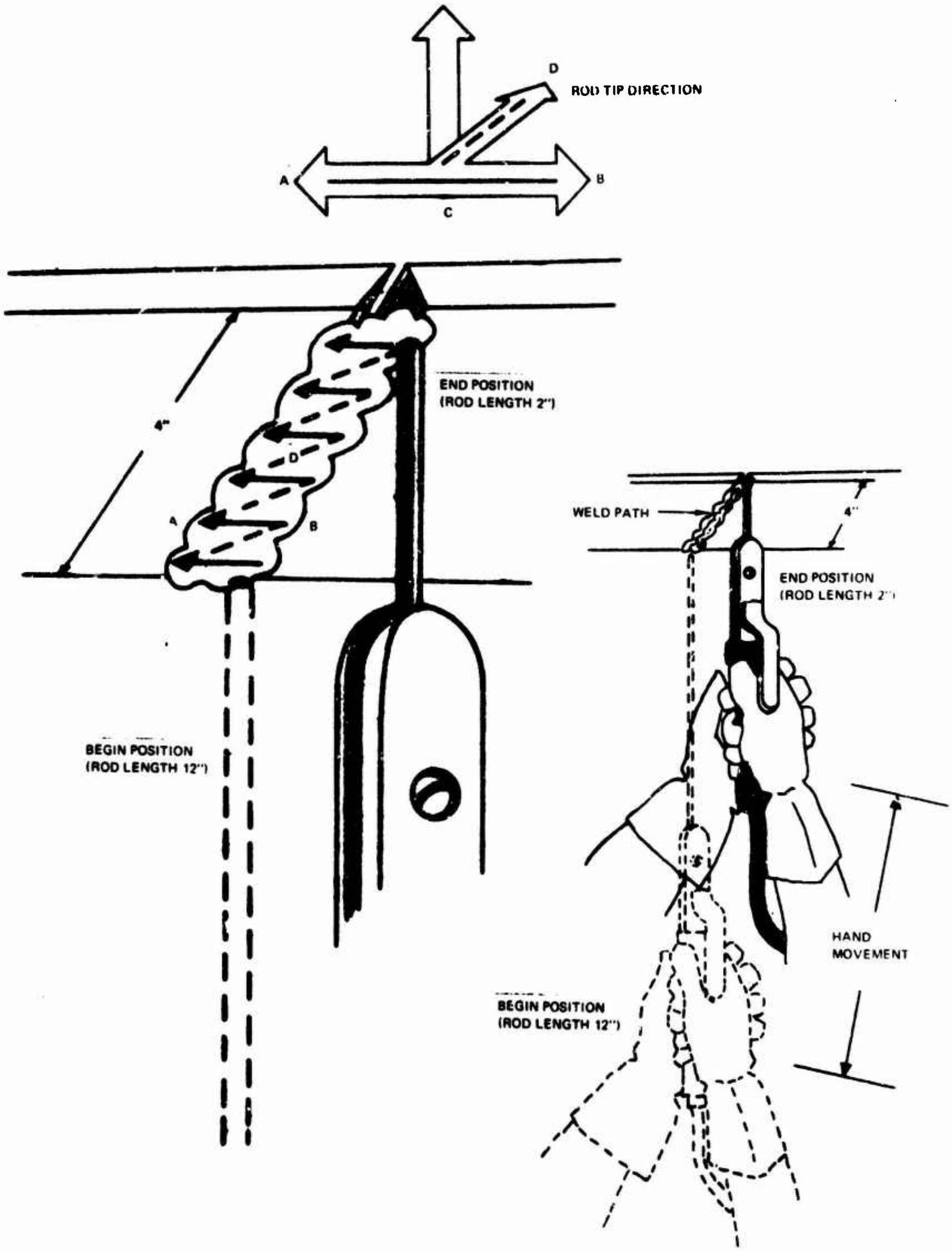

Figure 1. Welder movement while arc-welding one pass and consuming 10 in. of electrode (not to scale).

2. He pushes his arm upward to maintain the correct arc length as the electrode melts away (from C to E in Figure 1).

3. He holds his hands constant, while continuously adjusting his arms to maintain a fixed rod angle with respect to the weld surface (not shown).

In normal Navy training after the trainee is given a demonstration of the procedure, he retires to a booth and practices by running weld passes that take about 1 minute each. After the completion of each pass, it can be evaluated as good or bad. As can be expected, the trainee's initial weld passes are generally unacceptable, and it is usually impossible to determine what caused the unacceptable condition. Initially, the trainee is not able to process the exteroceptive and proprioceptive feedback cues inherent in the task. Also, the nature of the task precludes the instructor from observing the trainee's performance as he welds. Thus, the trainee has no way of knowing which of the many defined parameters he is exceeding as he learns to weld. Appendix A is an analysis of welding skill development.

The Welding Simulator

Configuration[2]

Structurally, the simulator resembles actual shielded metal arc (SMA) welding equipment and can be used in any welding position. As illustrated in Figure 2, it consists of three major units: (1) the stinger, a motor-driven device similar in form, weight, and purpose to an actual electrode holder and the consumable electrode (rod); (2) the track unit, a motor-driven target that simulates the welding path; and (3) the control unit, a unit that houses error sensors, digital recorders, and associated electronics that provide immediate operator feedback. The welding functions monitored by these sensors are length of arc, manipulation of the molten puddle (weave), and angle of electrode.

The trainee holds and manipulates the simulator stinger unit in the same way that he would handle an actual stinger. However, his efforts do not result in a weld but in feedback cues that inform him of his progress in acquiring one or a combination of the three basic welding behaviors.

[2]This discussion is extracted from Abrams, Safarjan, & Wells, 1973.

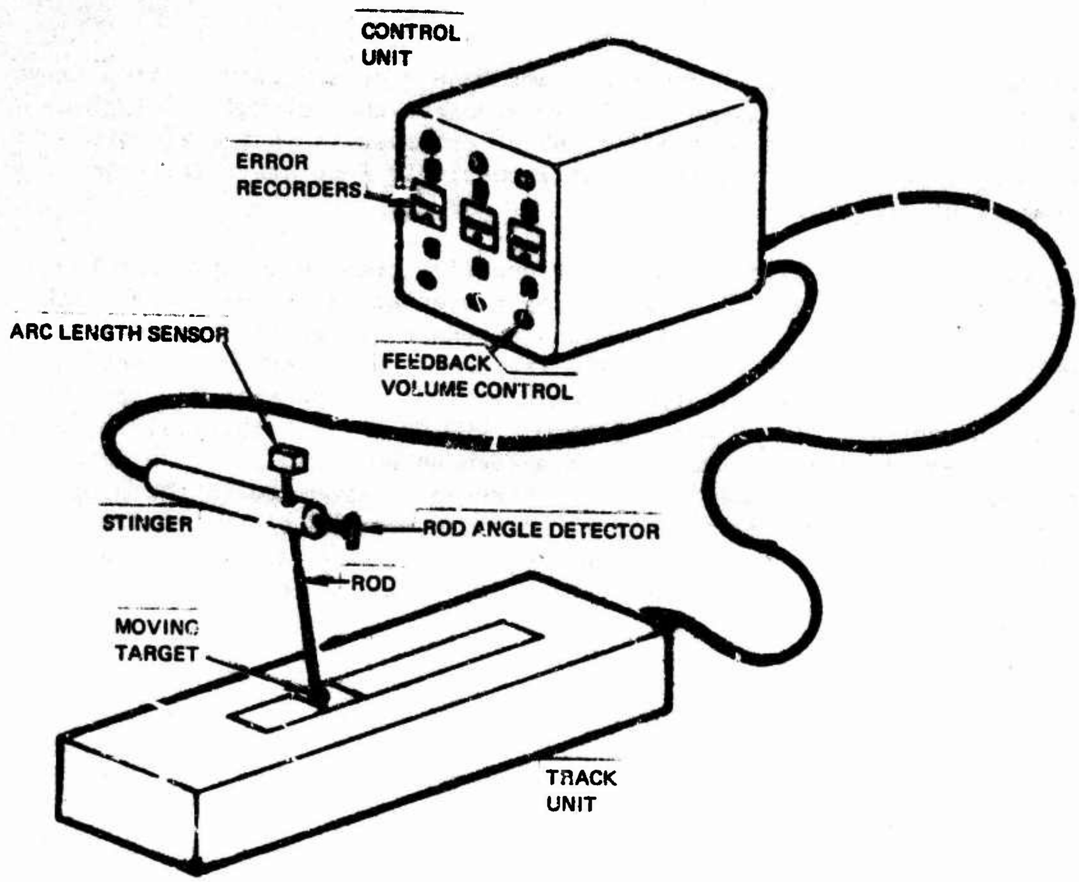

Figure 2. Welding simulator configuration.

Feedback Cues

As noted, a major obstacle to acquiring the arc welding skill is the trainee's inability to know which of the many parameters he is exceeding and when. With the simulator, it was hypothesized that this obstacle would be minimized by combining augmented feedback on the basic components of the welding task with the cues inherent in welding. This feedback is achieved in the following manner:

1. Arc Length. To provide proper proprioceptive cues, the electrode recedes at a rate equivalent to that at which an electrode melts under normal welding conditions. If the trainee fails to maintain the proper arc length (1/16-to-3/16 in.), augmented feedback is provided as follows: (1) the electrode stops receding, (2) the electronically generated "crackling, hissing" sound which resembles that of a burning electrode

terminates, and (3) the light that corresponds to arc illumination extinguishes. These go-no-go qualities simulate the natural welding environment--that is, an excessively short arc results in the electrode becoming stuck in the puddle and an excessively long arc results in breaking of the arc.

2. Weave. To develop the proprioceptive cues resulting from the side-to-side welding motion (including pauses at each side), the track duplicates the precise dimensions and speeds required to produce a quality weld (see Appendix A). The trainee aims the stinger-electrode at the track, and any deviation from the side-to-side movement results in an augmented feedback tone of about 1000 Hz. While the trainee follows these movements (rather than initiate them as he would do in an actual welding situation), simulation permits repeated exposure to the proprioceptive cues that normally would be received only after the trainee had learned to weld. Much reinforcement of incorrect behavior is thus eliminated, and the trainee can spend his time in the correct stimulus condition.

3. Angle of Electrode. As in weave, the proper stimulus condition for angle of electrode is present only after the trainee has developed his welding skill through a laborious trial-and-error process. This angle is defined as that between the electrode and the item welded relative to the direction of the weld. With the simulator, when the trainee fails to keep the angle of electrode within the allowable tolerance of 5-to-15 degrees, a tone of about 3000 Hz is presented until the angle is corrected.

The sensitivity of the feedback sensors can be adjusted for each of the three welding skill components. Thus, it is possible to shape behavior by allowing greater tolerance during the initial acquisition phase than during the later stages of skill development. Feedback can also be used selectively by providing cues exclusive to one welding component, and then integrating them with cues provided for the second and third components.

Method

Subjects

The subjects (Ss) were Hull Maintenance Technician (HT) Fireman and Fireman Apprentice trainees enrolled in the HT "A" School, San Diego, between 20 September and 15 November 1973. Over this period, 36 inexperienced welding trainees were randomly selected to particiapte in the experiment. These Ss were given a pre-experimental orientation and two 5-minute pretest trials on the apparatus. Based on the pretrial scores, Ss were matched and assigned to either the experimental (E) or control (C) group for an interval of approximately 12 days.

Apparatus

Both E and C groups received identical weld shop instruction in the arc-welding shop of the HT "A" School, used identical welding machines and associated materials, and performed the same weld projects. Additionally, the E group practiced on the simulators in 4x4x8 ft. booths similar in size and configuration to the weld-shop booths (see Figure 3). Each booth had an adjustable fixture for mounting the track unit to correspond with the various welding positions the trainee practiced in the arc shop. The control unit and a timer to measure trial length were positioned outside the booth for ease in recording data.

The feedback sensor circuits were adjusted to provide feedback and record errors when certain parameters were exceeded. Feedback delays for both weave and angle error sensors were set at 0.5 second, which meant that the trainee could be off target, or exceed rod angle limits, for up to 0.5 second before the tone would sound. There was no temporal delay for arc length error.

Criterion Test

It was desired that the criterion test should measure a unit of learning that incorporated the skills required in quality welding and yet had an objective that could be attained by an inexperienced trainee in a short time. The 70-hour learning unit on overhead and V-butt welding from the Class "C" Welding School's Plate Course came closest to meeting these specifications.

In this unit, the trainee learns how to arc weld, with the E-6011 electrode, two 5"x6"x3/8" mild steel plates butted together with a backing strip (see Figure 4) in both the overhead and vertical positions.

After practicing each learning task for approximately 28 hours, the trainee takes the final criterion test which consists of welding a test plate in about 7 hours.

Although this 70-hour learning unit was considerably more difficult than ongoing "A" School units, the "A" School agreed to add it to its curriculum for purposes of the evaluation. However, only 50 hours were allocated for the unit. Upon completion of the project, three instructors visually graded the test projects independently, using standard criteria (i.e., from a maximum possible score of 100, points were deducted for undercut, cracks, irregular bead appearance, lack of fusion, and excessive build-up). This was done because the "A" School did not have a radiographic capability nor were grinders available to properly prepare the test plates for radiographic testing. Because there was instructor agreement in terms of ranking the projects, the final score was obtained by averaging the grades of the three instructors.

Arc Welding Shop

Simulator Practice

Figure 3. Arc welding shop practice compared to simulator practice.

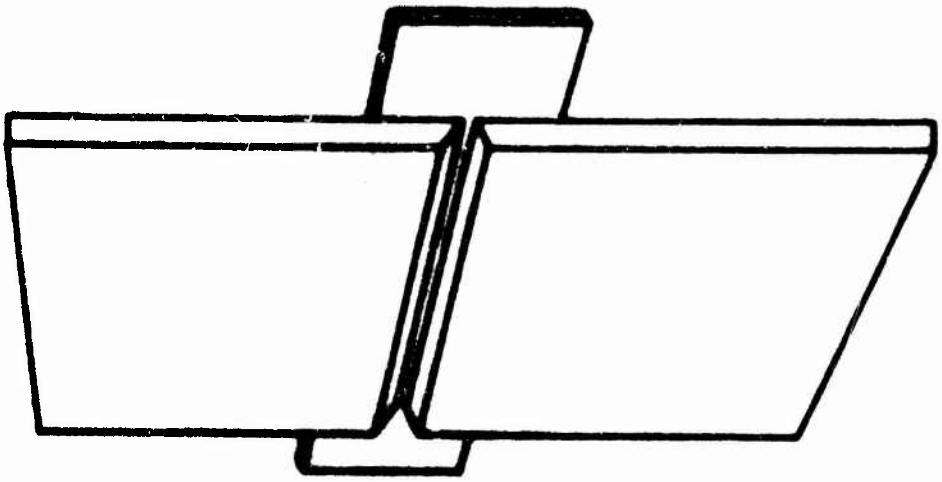

Figure 4. Mild steel plates butted together.

Procedure

Initially, all Ss were given a pre-experimental orientation and two 5-minute pretrials on the simulator. The Ss then reported to the arc shop where basic arc-welding procedures and shop safety were described. At this point, the S was permitted to progress through the program at his own rate, providing he did not spend more than 25 hours each on overhead and vertical welding. All Ss remained in the arc shop for the initial weld learning task, which involved striking and holding an arc and running beads in the flat position. The C and E groups continued on to overhead and vertical V-butt welding. The C group trainees spent their time in the arc welding shop whereas the E group alternated hours between the arc shop and simulator laboratory.

In the simulator laboratory, the 1-hour sessions consisted of three trials. To assure that each trainee received equal simulator practice, trial time was measured in real arc time (i.e., the total time that a proper arc length was maintained). Trial and intertrial lengths were 9 and 3 minutes, respectively. Trainees were given about a 10-minute rest after the third trial. Simulator scores on arc length, angle, and weave were recorded from the digital counters at the end of each trial, thus allowing a record to be kept of the trainees' progress. Because of variations in the operating characteristics of the prototype simulators, each subject was assigned his own device for the duration of the experiment. The percentage of improvement in each of the variables of simulator performance for each position was recorded for comparison with the respective test plate grades from the welding shop. This was computed by the percent gain of possible gain method No. 1 (McGraw, 1955).

Upon completion of each project in the weld shop, the test plate was sent to the simulator laboratory for coding and storage until the experiment was completed. At that time, the instructors graded all test plates, which assured that a blind grading procedure was followed.

For each trainee, records were kept of total training time and how that time was spent. In the weld shop, time was recorded for (1) welding practice (burning rod time), (2) performance of the requisite ancillary behaviors (e.g., setting up, quenching, chipping, and wire brushing), and (3) breaks (both scheduled and unscheduled). In the simulator laboratory, time was recorded for (1) simulator practice, (2) performance of the requisite ancillary behaviors (e.g., resetting rod and track, incorrect arc time, recording data, and adjusting equipment), and (3) breaks (scheduled breaks, intertrial rest, and unscheduled interruptions). Data on weld practice and all simulator behaviors were obtained by real-time measurements using timers attached to each machine. The remaining data were obtained by observational sampling of behavior throughout the training period.

Results

Criterion scores were evaluated by an analysis of variance, as shown in Appendix B. The mean scores were significantly higher for the E group They were 86.3 and 77.4, respectively, for the E and C groups on the overhead test plates, and 90.3 and 80.1 on the vertical test plates. The higher vertical scores for both groups reflect positive transfer from the overhead training, which preceded the vertical practice.

Correlations were computed between overhead test plate grades and simulator measurements of percentage of improvement for arc, track, and combined arc-track. The correlations were .73 for arc, .62 for track, and .79 for combined arc track.

Similar correlations could not be run for the vertical project because Ss finished this project prior to the collection of sufficient simulator progress data. This was a result of insufficient control over ongoing weld-shop procedures. In addition, angle error data were not computed since the angle sensor circuitry was not completely operational until the experiment was partially completed.

Table 1 shows the mean training time for both groups on the two projects used as criteria (overhead and vertical V-butt welding). Table 2 indicates mean total training time for these projects and identifies mean time devoted to the various behaviors. The tables show that mean total training time for both groups was essentially the same.

TABLE 1

Average Amount of Time Spent on Each Project in the Unit of Instruction

Projects	C Group $\bar{X}$ Hours	E Group $\bar{X}$ Hours
OVERHEAD	24.8	25.0
VERTICAL	11.4	11.4
TOTAL	36.2	36.4

TABLE 2

Distribution of Training Time for Overhead and Vertical Projects

Behavior	E Group		C Group	
	$\bar{X}$ Hours	% of Total Time	$\bar{X}$ Hours	% of Total Time
SIMULATOR LAB:				
Practice on Simulator	10.6	29.1		
Ancillary Behaviors	2.3	6.3		
Breaks	4.8	13.2		
TOTAL TIME - SIMULATOR LAB	17.7	48.6		
WELD SHOP:				
Practice Welding	4.0	11.0	6.0	16.6
Ancillary Behaviors	11.8	32.4	24.0	66.3
Breaks	2.9	8.0	6.2	17.1
TOTAL TIME - WELD SHOP	18.7	51.4	36.2	100
TOTAL TIME - SIMULATOR LAB and WELD SHOP	36.4		36.2	

Discussion

The E group performed significantly better than the C group on both criterion tests. Thus, there is strong evidence for positive transfer from the simulated task to the actual task. The simulator apparently provides more efficient practice on the complex behaviors involved in performing the task (i.e., rod feeding, rod angle, puddle manipulation, and their integration) than does practice on the task itself. This is a result of providing augmented feedback not available when practicing the task. In addition, the simulated task facilitates the integration of the various complex behaviors in welding by providing feedback in three different dimensions not available in performing that task. Table 2 shows that the E group practiced a mean of 14.6 hours on these behaviors (i.e., 10.6 hours simulator practice plus 4.0 hours weld practice) compared to a mean of 6.0 hours for the C group.

A difference in practice time, which favored the E group, also occurred in the weld shop. This probably resulted from the positive relationship existing between welding proficiency and welding practice time, i.e., the less proficiency the trainee has, the more mistakes he makes, which, in turn, results in increases in ancillary and nonproductive behaviors (Abrams and Carr, 1971). Additional evidence for positive transfer from the simulated task to the real task comes from the high correlations between the percentage of improvement in simulator performance and overhead test plate grades.

Besides the angle sensor circuitry problems previously identified, the prototype device experienced certain problems requiring minor modifications. Although these difficulties did not appreciably affect the quality and reliability of the data, increased reliability must be attained for this device to be used on a wide scale.

The potential advantages of the simulator may extend beyond increased welder performance. A substantial reduction in training time should be obtained in longer advanced welding courses (e.g., "C" School courses run from 10 to 24 weeks). However, even if the potential time savings are ignored, rotation of personnel between simulators and welding machines should provide for reductions in material costs (e.g. welding machines, electrodes, metals) and increased training capabilities.

The use of the device provides substantial energy savings. A welding machine consumes approximately 5,175 watts compared to approximately 24W for the simulator. Thus, one welding machine uses 215 times the energy used by one simulator, or, as much power as 215 simulators. The C group trainees consumed an average of 31,050 watt hours (6 hours at 5,175W) compared to an average of 20,954 watt hours (4 hours at 5,175W and 10.6 hours at 24W) for the E group trainees. The average difference in consumption was 10,096 watt hours. If all 120 trainees (usual on-board count at the HT "A" School) alternated between a simulator and welding machine, a savings of 1,211,520 watt hours would be realized each 2-week interval, or 30,288,000 watt hours per year (50 weeks per year).

Conclusions and Recommendations

From the results of this study, it is concluded that (1) a physically complex, continuous, three-dimensional psychomotor skill can be acquired more efficiently with simulated-task augmented feedback than with the feedback provided by performing the task itself, and (2) the prototype device developed can be utilized effectively to train arc welders.

The simulator trainees not only performed better but used 215 times less energy, substantially less welding material, and spent approximately half as much time in the welding shop as their counterparts. Thus, if the device were used on a large scale, welding schools would realize substantial savings in energy consumption, material costs, and greatly increased training capabilities (i.e., the number of students could possibly be doubled by rotating blocks of trainees between simulator and weld-shop practice). However, prior to recommending large-scale purchase of the present device, it should be refined. Also, if it is to be used aboard ship, it should be engineered to be compatible with the shipboard environment (e.g., ruggedized and built in accordance with applicable military specifications).

The device can be used to maintain welding skill in circumstances where actual welding practice is not possible - for example, aboard submarines where requalification failure rates for machinist mate welders are about 60 percent (Abrams, Bishop, LeRoy, 1969). The simulator may also function as a quantitative measuring device to select the most promising trainees for welding school.

Further research using the device as a vehicle to study the use of simulated-task, augmented feedback to acquire physically complex, continuous, three-dimensional psychomotor skills should be expanded to include such skills as silver brazing, precision soldering, or fusing and defusing ordnance. Variables such as trial length, session length, mass versus distributed practice, ratio of use of the simulated-task device to the task itself, and shaping and fading should be investigated.

REFERENCES

Abrams, M. L., Bishop, J. A., and LeRoy, H. D. An experimental model welding curriculum for the Class "C" Welding school, San Diego: Naval Personnel Research Activity, September 1969. (Research Report SRR 70-5.)

Abrams, M. L., and Carr, M. N. Development and evaluation of experimental arc welding training procedures and techniques. San Diego: Naval Personnel and Training Research Laboratory, September 1971. (Research Report SRR 72-6.)

Abrams, M. L., Safarjan, W. R., and Wells, R. G. Description and preliminary training evaluation of an arc welding simulator. San Diego: Naval Personnel Training Research Laboratory, June 1973. (Research Report SRR 73-23.)

Annett, J. The role of action feedback in acquisition of simple motor responses, Journal of Motor Behavior. 1970, 2, 217-221.

Annett, J., and Clarkson, J. K., The use of cuing in training tasks, Orlando: NAVTRADEVCEN 3143-1, April 1964.

Annett, J., and Paterson, L. The use of cuing in training tasks: Phase II, Orlando: NAVTRADEVCEN 4119-1, February 1966.

Annett, J., and Paterson, L. The use of cuing in training tasks: Phase III, Orlando: NAVTRADEVCEN 4717-1, August 1967.

Bilodeau, I. M., and Rosenquist, H. S. Supplementary feedback in rotary-pursuit tracking, Journal of Experimental Psychology, 1964, 68, 53-57.

Blaiwes, A. S. Transfer as a function of task difficulty in pursuit-rotor and paired-associate learning, Orlando: NAVTRADEVCEN IH-172, October 1970.

Blaiwes, A. S., and Regan, J. J. An integrated approach to the study of learning, retention, and transfer - a key issue in training device research and development, Orlando: NAVTRADEVCEN IH-178, August 1970.

Briggs, G. E. On the scheduling of training conditions for the acquisition and transfer of perceptual - motor skills, Orlando: NAVTRADEVCEN 836-1, December 1961.

Briggs, G. E. Research on augmented feedback and the acquisition and transfer of skill, Orlando: NAVTRADEVCEN 836-3, September 1962(a).

Briggs, G. E. Training for partial-panel control skills, Orlando: NAVTRADEVCEN 836-2, November 1962(b).

Briggs, G. E., and Wiener, E. L. Fidelity of simulation: I. Time sharing requirements and control loading as factors in transfer of training. Orlando: NAVTRADEVCEN 508-5, October 1959.

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Curriculum for plate welders, Class C, NAVPERS 93522, 1970.

Fleishman, E. A., and Rich, S. The role of kinesthetic and spatial-visual abilities in perceptual-motor learning, Journal of Experimental Psychology, 1963, 66, 6-11.

Gagne, R. M. Simulators. In R. Glaser (ed.), Training Research and Education, Pittsburgh; University of Pittsburgh Press, 1962.

Gibson, K. L., and Abrams, M. L. Development, conduct, and evaluation of experimental Class "C" Welding School training program for plate welding: I. Intensive observation of an experimental welding class, San Diego: Naval Personnel and Training Research Laboratory, May 1970. (Research Report SRR 70-29.)

Goldstein, M., and Rittenhouse, C. H. Knowledge of results in the acquisition and transfer of a gunnery skill, Journal of Experimental Psychology, 1954, 48, 187-196.

Gordon, N. B., and Gottlieb, M. J. Effect of supplemental visual cues on rotary pursuit, Journal of Experimental Psychology, 1967, 75, 566-568.

Hammerton, M. Factors affecting the use of simulators for training, Proceedings of IEE, 1966, 113, 11, 1881-1884.

Karlin, L. Effects of delay and mode of presentation of extra cues on pursuit-rotor performance, Journal of Experimental Psychology, 1965, 70, 438-440.

McGraw, L. W. Comparative analysis of methods of scoring tests of motor learning, The Research Quarterly, 1955, 26, 440-453.

Naylor, J. C., Briggs, G. E., and Buckhout, R. Long-term skill transfer and feedback conditions during training and rehearsal, AMRL-TDR-63-136, December 1963.

Regan, J. J. Tracking performance related to display control configurations, Orlando: NAVTRADEVCEN 322-1-2, January 1959.

Smode, A. F. Recent developments in training problems, and training and training research methodology, In R. Glaser (ed.), Training Research and Education, Pittsburgh: University of Pittsburgh Press, 1962.

Wexley, K. N., and Thornton, C. L. Effect of verbal feedback of test results upon learning, The Journal of Educational Research, 1972, 66(3), 119-121.

Williams, A. C., and Briggs, G. E. On-target versus off-target information and the acquisition of tracking skill, Journal of Experimental Psychology, 1962, 64, 519-525.

APPENDIX A

Analysis of Welding Skill Development

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Analysis of Welding Skill Development[1]

This analysis is based on trainee observation, instructor experience, and related research on skill learning. Welding skill development essentially was found to be a learning process in which the desired skills must be incorporated into the behavioral patterns of the trainee despite a complex stimulus situation, interference from mistakes and old habits, and poor feedback. The welding trainee is first shown by the instructor what good welding looks like. He must then, through practice, incorporate the demonstrated behavior into his own behavioral patterns. In other words, he must learn to make the correct movement to a complex stimulus situation which includes aspects of the welding process and also the trainee's own kinesthetic feedback. Knowledge of results is provided by the welding process. Using the side-to-side welding technique as an example, the welder makes a zig-zag movement in which he pauses for a certain period at the sides of the movement. The length of the pause is determined by the appearance of the molten puddle. If he pauses too long, the molten puddle will become too large. If he fails to pause, an error known as undercut will occur. The experienced welder makes this zig-zag movement in a rhythmic motion that shows he is also using kinesthetic feedback to integrate and anticipate the required movements.

Further analysis of the welding skill will be specifically directed to its main components: (1) incorporation, (2) interference, (3) discrimination of the exteroceptive cue situation, (4) feedback, (5) the circular feedback loop of the welding process, (6) positioning, and (7) wrist action in the side-to-side motion.

1. Incorporation. On the first day in the laboratory, the instructor demonstrated to an inexperienced trainee how to strike and maintain an arc. The trainee then attempted to do it. He fed-in the electrode in steps. After practice the trainee began to feed-in the electrode smoothly.

The demonstration deals with the exteroceptive stimuli or cues of the welding process that the trainee must respond to and the results he is trying to achieve. An instructor cannot give the trainee the feel of running the electrode. He can only show the trainee what a good welding job looks like and provide him with a general idea of what movements he must make. The trainee then sets out to do what he has been shown. In his first attempts, his reaction must be entirely dependent on the exteroceptive cues from the welding process. His movements, however, provide

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[1] This analysis is extracted from Gibson and Abrams, 1970.

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proprioceptive cues which, as he continues to practice, can be used to anticipate what must be done next and to integrate his movements into a continuous pattern. In the example above, proprioceptive feedback apparently enabled the trainee to maintain a steady feed-in rate after practice.

2. Interference. Even after receiving considerable individual attention from the instructors, some trainees rapidly revert back to their old bad habits. In an example of this from the present experiment, one trainee, who was able to feed-in the electrode smoothly, nevertheless, required repeated help before he started to use the proper side-to-side technique. An explanation may be that the trainee's own imperfect practice causes interference. That is, the trainee sets out to do what the instructor has shown him, but he cannot do it. His own failure provides interference that causes him to forget the instructor's demonstration. Because of interference from his mistakes and old habits, there is a good chance that the trainee will become confused rather than succeed in incorporating the demonstrated behavior. Of course, the trainee may have failed to attend to important aspects of the instructor's demonstration. In this case, or the case of unsuccessful incorporation, the trainee's progress is impeded.

3. Discrimination of the exteroceptive cue situation. The discriminations the welding trainee must learn to make are complex. For instance, he is instructed to maintain an 1/8-inch arc length with the 6011 electrode, which requires that he learn to discriminate cue situations indicating correct/incorrect arc length. There are many cues which indicate whether or not the correct arc length is being maintained. In some welding positions, the arc length can be viewed directly; however, this procedure is not recommended because good welding required constant reference to the puddle. Other cues, considerably more complex for the trainee to discriminate, include the amount of spattering, brightness of the puddle, and sound of the arc.

4. Feedback. The trainee is provided with three sources of feedback or knowledge of results. One source is from the welding process itself. The previous section gives some idea of the complexity of the information the welding process cue situation provides. For the inexperienced trainee, this information certainly does not provide clear feedback on his actions. Another source of feedback is from the testing or inspection of the completed weld. The problem here is in the delay of feedback (hours or even days). It is, therefore, doubtful that the latter feedback is important in the learning process other than as a motivator to get the trainee to try to find out what he did wrong. The third source of feedback comes from the instructor observing the trainee weld. Providing such feedback required a large amount of instructor time and effort. Also, observing the trainee in some welding situations is quite difficult.

5. The circular feedback loop of the welding process. A major source of the difficulty in learning welding may be in the circular nature of the task. The movements required depend on the cue situation, but the cue situation is a result of the movements the trainee just made - that is, acquiring welding skill involves learning to make the right physical movement to a particular cue situation. The cue situation consists of exteroceptive feedback from aspects of the welding process and proprioceptive feedback, both of which are a result of previous movements by the trainee. If the trainee's inability produces a cue situation grossly different from the desired, he cannot be learning the stimulus-response relationships of good welding.

6. Positioning. Many of the trainees would do a good job on the first half of their pass and then become unsteady. Apparently a concept the trainee had to learn was to position and support himself so that he could use the entire electrode without having to make an inappropriate postural adjustment. This seemed to be more than a trivial thing to learn, and apparently involved considerable experimentation on the part of the trainees. Another specific point was that when the beginning trainee welds in the vertical position, he tends to raise only his forearm as he continues up the plate. This throws the angle of the electrode off. The trainee must be taught to raise his whole arm, or arm and body, to prevent changing the angle of the electrode.

7. Wrist action in the side-to-side motion. In using the side-to-side motion, the beginning trainee has a tendency to use both arms or the whole welding arm to make the side-to-side motion. This does not work, because the proper side-to-side motion involves going rapidly across the center of the puddle and holding the sides. If the whole arm is used, too much time is spent in the center of the puddle, which leads to excessive buildup. The side-to-side motion must be made by using the wrist, and the trainee may require considerable help in learning this technique.

APPENDIX B

Analysis of Variance Tables

APPENDIX B

Analysis of Variance Comparing Overhead Test Plate Scores of the Experimental and Control Groups

Source	*df*	*MS*	*F*
A	1	640.9	6.25*
S/A	34	102.4	
TOTAL	35		

* $p < .05$

Analysis of Variance Comparing Vertical Test Plate Scores of the Experimental and Control Groups

Source	*df*	*MS*	*F*
A	1	950.7	14.8*
S/A	34	67.49	
TOTAL	35		

*$p < .01$

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