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ABSTRACT

A prototype arc welding training simulator was designed to provide immediate, discriminative feedback and the capacity for concentrated practice. Two randomly selected groups of welding trainees were compared to evaluate the simulator, one group being trained using the simulator and the other using conventional practice. Preliminary data indicated that with substantially less welding practice and combined welding/simulator practice, simulator trainees performed as well as conventionally trained subjects. Appendixes include an analysis of welding skill development, a description of the simulator, and simulator modifications and new features. (Author/NH)

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DESCRIPTION AND PRELIMINARY TRAINING EVALUATION OF AN ARC WELDING SIMULATOR

by

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June 1973

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SUMMARY AND CONCLUSIONS

Problem

This report presents the initial description and evaluation of a prototype arc welding training aid (the simulator) that was designed to provide immediate, discriminative feedback and the capacity for concentrated practice. Neither of these essential learning qualities are found in conventional arc welder training nor are they provided for by the welding process.

Background and Requirements

Historically, the principal reinforcing variable in the acquisition of arc welding skills has been summary feedback, i.e., the knowledge of results provided the trainee by the instructor. This reliance on secondary source information was inevitable because of the complexity of the welding task and the ambiguity of the exteroceptive and proprioceptive feedback cues. The temporal delay between a completed weld pass and feedback or knowledge of results varied from minutes to several days. The delay depended on the availability of instructors for visual inspection or the time required to process the welded project if destructive or nondestructive tests were used. Because an inverse relationship generally exists between performance, and delay and quality of reinforcement, it was assumed that immediate, discriminative knowledge of results would increase the reinforcing properties of welding feedback and therefore increase training efficiency.

Equally important as feedback, is the need for efficient, concentrated practice. With traditional welding training this was not possible because approximately 90% of the trainee's time was necessarily spent preparing weld surfaces for subsequent weld passes. These preparatory tasks (i.e., setting up, quenching, cleaning, and chipping) are easily learned and are not directly related to welding skill acquisition. It was therefore anticipated that training effectiveness would improve if a device could be constructed which would simulate welding while eliminating the obstacles to acquisition, which were part of the welding process.

Approach

A training aid resembling actual arc welding equipment was designed and built. It consists of a motor-driven device representing the electrode holder (stinger) and welding electrode (rod), a motor-driven target representing the welding path, and a box housing digital recorders and error sensors providing immediate operator feedback. The welding functions monitored by the sensors are length of arc, manipulation of the molten puddle (tracking) and angle of electrode.

To evaluate the simulator, two groups of naive welding trainees were compared. The trainees were randomly selected from four classes enrolled in the HT "A" School, San Diego, between 4 May and 18 September 1972. The 14 members of the experimental group were trained according to this schedule: (1) half-time welding practice; (2) quarter-time simulator practice; and (e) quarter-time waiting to use the simulator. The 13 control group members received conventional welding practice. Upon completion of a 6-1/2 day phase on vertical V-butt welding, performance was evaluated based on visual and radiographic nondestructive tests.

Findings, Conclusions, Recommendations

Recognizing the constraints inherent in an evaluation of a prototype vehicle (e.g., limited sample size, electromechanical failures), it appears that the simulator may provide the desired welder practice. Even with substantially less welding practice and combined welding/simulator practice, the simulator trainees performed as well as the conventionally trained subjects. It also appears that the potential advantages of the simulator go beyond reduced training-time and/or increased welder performance. The simulator provides definite advantages in terms of material savings (e.g., welding machines, power sources, electrodes, and metals) and increased training capabilities. Large scale use of the simulator could possibly: (1) enable welding schools to double the number of students by rotating blocks of trainees between simulator and weld-shop practice, (2) provide the means for ongoing shipboard training under conditions where actual welding practice is not feasible, and (3) be used as a quantitative measuring device to select men with the greatest potential for success in welding schools.

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DESCRIPTION AND PRELIMINARY TRAINING EVALUATION OF
AN ARC WELDING SIMULATOR

A. Introduction

1. Problem

This report presents the initial description and evaluation of an arc welding simulator developed by the Naval Personnel and Training Research Laboratory (NPTRL) in cooperation with the Service School Command, San Diego (SERVSCOLCOMSDIEGO). Currently, over 30 weeks of training are required for trainees to develop that level of welding competency required by today's Navy. Qualities such as complete absence of contamination and perfect fusion are no longer simply desirable but are demanded as the jobs required of a welder become more critical. The simulator was developed in answer to this growing need for quality welders by providing a vehicle through which the effectiveness of training (i.e., training-time and excellence) could be improved. The anticipated benefits of incorporating this simulator into conventional training programs came from two qualities the simulator provides which are not currently found in welder training: (1) immediate, discriminative feedback; and (2) the capacity for concentrated practice.

While the intent of this report was to provide a general description and initial evaluation of the arc welding simulator, specific questions to be answered by the present research included: (1) Does the simulator, as configured, appear to provide the desired welder training? and (2) If not, does it appear that the simulator, with modification, would provide the desired training?

2. Background

Historically, the principal reinforcing variable in the acquisition of welding skills has been summary feedback, i.e., the knowledge of results provided the trainee by the instructor. This reliance on secondary-source information was inevitable because of the complexity of the welding task and the ambiguity of the exteroceptive and proprioceptive feedback cues (Gibson & Abrams, 1970 - See Appendix A for an analysis of welding skill development extracted from this study.). The temporal delay between a completed weld pass and feedback (knowledge of results) varied from minutes to several days depending on: (1) the availability of instructors in the case of visual inspection, or (2) the amount of time required to process the welded project if destructive or nondestructive tests were used. Because it is commonly held in psychological literature (Kling & Riggs, 1971) that an inverse relationship exists between performance and delay and quality of reinforcement, it was assumed that immediate, discriminative knowledge of results would maximize the reinforcing properties of welding feedback and therefore increase training efficiency.

While the discriminative and temporal qualities of feedback would appear important to the acquisition of welding skills, another variable has been found to be equally important when combined with adequate feedback cues -- the capacity for concentrated practice. Both applied and experimental psychologists alike have stressed the importance of practice in the acquisition and maintenance of behavior (Hilgard & Bower, 1966). The definition of learning itself includes the concept of practice in order to differentiate changes in behavior resulting from maturation, fatigue, etc. Traditionally, however, up to 90% of the trainee's time was necessarily spent performing the ancillary tasks of setting-up, quenching, cleaning and chipping between weld passes. These time consuming tasks are easily learned and do not contribute to welding skill (Abrams & Carr, 1971). Because of the importance of practice to skill acquisition, it was anticipated that training effectiveness would be further increased if a device could be constructed which would simulate the welding process while at the same time eliminate the need to prepare weld surfaces for subsequent passes.

The general intent of welding simulation was to increase the training efficiency by eliminating obstacles to acquistion which were inherent in the welding process. A simulator, however, could provide additional secondary advantages which relate not only to acquisition but to maintenance of welding skills as well as its potential use as a selection device. For example, the stimulus control provided by simulation could be used to "shape" welding behavior (i.e., a gradual progression to complex behavior repetoires through successive approximation) or to "fade" stimulus support through gradual withdrawal thus making the trainee dependent on interoceptive and exteroceptive cues once the skill was acquired (Holland, 1960; Gagne, 1965). Further, the device could be used to maintain behavior in conditions where actual welding is inappropriate (e.g., submarines). This would be an obvious benefit for those individuals interested in requalifying for certification. And finally, a simulator might be used as a quantitative measuring device to select men with the greatest potential for success in welding schools.

B. General Description of the Welding Simulator

1. Preface

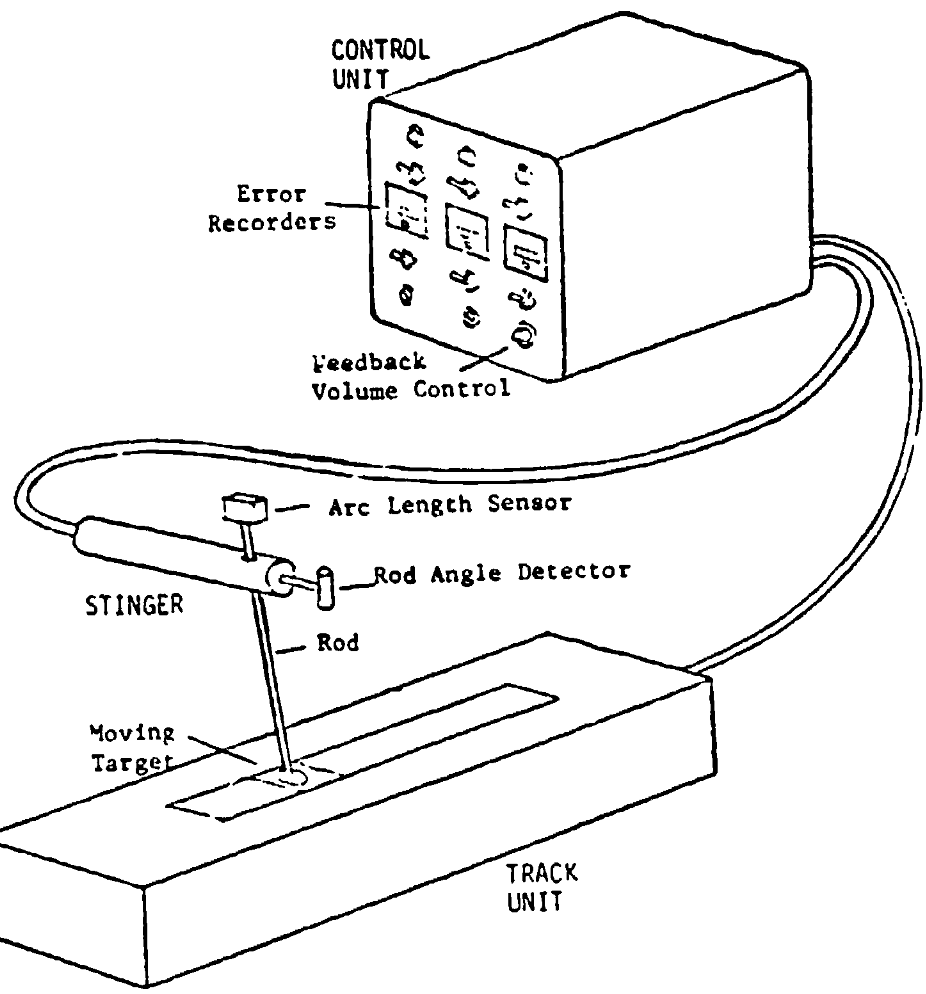
By definition, a simulator attempts to represent a real situation in which a set of operations are performed (Gagne, 1962). The increasing interest in simulation has come from: (1) the rising capital and operating costs of military and industrial equipment which prohibit the equipment's use in training and (2) the increasing complexity of equipment which demands involved training programs (Hammerton, 1966). To date, however, simulation has not been used to augment operations required in a complex perceptual-motor task (see Gagne, 1962). In effect, the simulator in question represents more than the "real situation" in that it provides an environment which is potentially more conducive to skill acquisition than

the existing one. However, it does not replicate all aspects of the physical welding environment nor does it supply all cues provided by the welding process, specifically, those associated with welder initiation of puddle movement. For this reason, actual welding practice is required in conjunction with simulator practice and the term 'simulator' may not be an appropriate one for the apparatus under consideration. However, it will be used rather than 'training device' to distinguish it from training equipment which has a rather restricted application.

The need for welding simulation was first recognized by Gibson and Abrams (1970) while conducting a four week experimental arc welding program designed to study the welding skill. Through observation and interaction with instructors and trainees at the Class "C" Welding School, Gibson and Abrams found that welders experience great difficulty in acquiring and integrating three basic skill components: (1) arc length, (2) weave, and (3) angle of electrode. The simulator was designed to be incorporated into conventional welding programs by providing supplemental training in these three basic skills.

2. Configuration

Structurally, the simulator resembles actual shielded metal arc (SMA) welding equipment and can be used in any welding position. As illustrated below, it consists of three major units: (1) a motor-driven device which is similar in form, weight, and purpose to an actual electrode holder (stinger) and the consumable electrode (rod); (2) a motor-driven target which represents the welding path; and (3) a box containing error sensors and recorders with the associated electronics for immediate operator feedback. The welding functions monitored by these sensors are length of arc, manipulation of the molten puddle (weave) and angle of electrode. (See Appendix B for a more detailed description.)



The simulator stinger unit is held and manipulated by the trainee as he would an actual stinger. His efforts, however, do not result in a weld but in feedback cues which inform him of his status in acquiring one or a combination of the three basic welding components.

3. Feedback Cues

It was noted earlier that one of the major deficits to acquisition of arc welding skills was the trainee's inability to process exteroceptive and proprioceptive cues inherent in the welding operation. With the simulator, this deficit is overcome, in part, by providing augmented or supplemental feedback on the basic components of the welding task. The augmented feedback is in the form of electronically generated off-target auditory cues which are provided for both weave and angle of electrode. A tone of about 3000 Hz is used for the former welding component and a "buzzing" sound of about 300 Hz is used for the latter. This augmented auditory feedback is combined with the cues which are a part of the welding operation in the following manner:

a. Arc Length - To provide proper proprioceptive cues, the electrode recedes at a rate equivalent to that which an E-6011 electrode melts under normal welding conditions. If the trainee fails to maintain the proper arc length (about 1/8 inch), the electrode stops receding, the electronically generated "crackling, hissing" sound which resembles that of a burning electrode terminates, and the light which corresponds to arc illumination extinguishes. These go no-go qualities simulate the natural welding environment in that: (1) an excessive short arc results in the electrode becoming stuck in the puddle and (2) an excessively long arc results in the loss of the arc.

b. Weave - To develop the proprioceptive cues resulting from the side-to-side welding motion used in welding, a track was developed which duplicated the precise dimensions and speed required to produce a quality weld (See Appendix A). The trainee aims the stinger-electrode at the track and deviation from the side-to-side movement results in the feedback tone described earlier. While the trainee follows, rather than initiates these movements as he would in the actual welding situation, simulation provides the opportunity for repeated exposure to the proprioceptive cues that would be received only after the trainee had learned to weld. Much of the reinforcement of incorrect behavior is thus eliminated and the trainee can spend his time in the correct stimulus condition.

c. Angle of Electrode - As in weave, the proper stimulus condition for angle of electrode (i.e., the angle between the electrode and the item welded as defined with respect to the direction of the weld) is present only after the trainee has developed his welding skill through a laborious trial-and-error process. The design of the simulator, which resembles that of an actual weld assembly, provides the proprioceptive and visual cues found in the welding environment and supplements them with auditory feedback. When the trainee fails to keep the angle of electrode

within the allowable tolerance (5° to 15°), a buzzer sounds and remains on until the angle is corrected. The additional auditory cue facilitates integration of the three welding functions by allowing the trainee to concentrate on the two more difficult welding components (i.e., weave and arc length) while receiving information on the status of his lead angle.

The sensitivity of the principal feedback sensors is adjustable 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.

C. Method

1. Design Restrictions

To answer the questions posed by the study, it was necessary to evaluate the physical design and training effectiveness of the simulator concurrently because of their mutual interdependence. As such, it was not possible to attain the rigorous degree of experimental control desired. Factors adversely affecting control included:

(1) The availability of just the prototype limited sample size and necessitated pooling data across several experiments because each experiment required at least three weeks to conduct and could accommodate only four simulator subjects.

(2) As anticipated in an initial evaluation of electromechanical equipment, failures were experienced which often required suspending simulator training for varying intervals and/or modifying the simulator. The modifications did alter the quality of the apparatus over experiments and the data may reflect this variation. Further, defects which developed may have adversely affected transfer of training from the simulator to the welding environment. For example, the track motion frequently became "jerky" and feedback cues may have reinforced an undesirable behavior.

(3) Since actual arc welding training experience during the conduct of the experiment was also integral to the experimental design, it was necessary to use subjects who were enrolled in formal welding training programs. However, because the majority of the trainees enrolled in the course were not a part of the experiment, it was agreed with the school that normal routine would not be disturbed. Consequently, class schedules and other administrative requirements frequently limited simulator running time, the subjects seldom received the required exposure to the simulator, and the procedure described in the following paragraphs represents the ideal rather than the actual experimental situation.

2. Subjects

Trainees were Hull Technician Firemen and Firemen Apprentices drawn from four classes enrolled in the HT "A" School, San Diego, between 4 May and 8 September 1972. From each of the four classes varying from 15 to 60 trainees, four naive subjects were randomly selected and assigned to the experimental (E) group and four to the control (C) group. The data from five subjects were removed from the analysis when it was later found that these trainees had prior welding experience. Thus the final *n* for this experiment was 27 with 14 and 13 in the E & C groups, respectively.

3. Apparatus

Because the simulator was designed to supplement rather than replace actual welding practice, both E and C groups received their traditional instruction in the arc welding shop of the HT "A" School. All subjects were assigned to the same type of welding machine and used the same brand of E-6011 welding electrode.

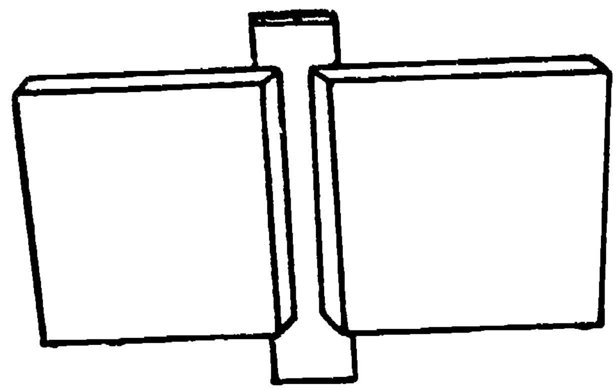
In order for the auditory feedback cues to be effective, simulator training was given in an unused classroom away from the din of the weld shop. Additionally, the trainee practiced on the simulator in a 6x4x4 foot wooden booth in order to be further isolated from any distractions caused by fellow trainees or experimenters. Feedback tones for weave and angle errors were set at .2 seconds and .4 seconds, respectively. This meant that the trainee could be "off-target" for up to .2 or .4 seconds before the tone would sound. There was no temporal delay for arc length error. When the arc length was not maintained within a 1/16" to 3/16" target range, rod consumption, as well as the primary auditory and visual cues, would terminate.

To enable the experimenter to record the number of angle, arc length and weave errors made by the trainees on each trial, all three feedback systems were connected to digital counters. In addition, a timer was connected to the arc length circuit to measure trial length. The timer was activated only when the arc length was in the allowable range.

4. Criterion Test

It was desired that the criterion test measure a unit of learning which incorporated the features required in quality welding and yet could be attained by a naive trainee in as short a time frame as was possible. Nearest to these specifications was the 10-day unit on vertical V-butt welding from the Class "C" Welding School's Plate Course (NAVPERS, 1970, pp. 23-27).

For 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 illustration).



After practicing welding this project for approximately nine days, the trainee welds one final project, referred to as the test plate (the criterion test), which is scored by means of visual and radiographic nondestructive tests.

Although this 10 day learning unit was considerably more difficult than ongoing "A" School units, the "A" School permitted adding the project for purposes of the evaluation; however, only 6-1/2 days were allocated for the unit.

5. Procedure

To evaluate the training potential of the simulator, two groups of naive arc welding trainees were compared. The E group was trained according to this schedule: (1) half-time - welding practice and instruction; (2) quarter-time - simulator practice; and (3) quarter-time - simulator inter-trial intervals. The latter component, length of inter-trial interval, was considerably more excessive than desired but it did permit running subjects in pairs for more efficient use of the simulator. The C group received conventional welding practice and instruction.

Total training time extended over a period of 15 working days. After spending the first morning of training on programmed materials devoted to basic arc welding and safety, both groups of trainees moved into the welding shop to begin their practical training. From this point on, their instruction was in the form of group and individual demonstrations and oral reviews of their welds. Trainees were allowed access to only one designated instructor in order to assure consistency of instruction both among subjects and between the simulator and welding shop. The initial project involved striking and holding an arc and welding beads on a plate in the flat position. After 1½ days of flat welding the trainees spent approximately two

days practicing welding a tee-joint project in the horizontal position. This project was a required school project but served no useful purpose with respect to the evaluation. The next 6-1/2 days, upon which the simulator evaluation is based, involved welding in the vertical position. The first vertical project was a simple tee-joint. After the trainee became accustomed to the vertical position, he moved on to vertical V-butt joints. Upon completion of the vertical training phase, the subjects were required to weld two final vertical V-butt test plates. Criterion scores were assigned to them by means of visual and radiographic nondestructive tests, and results of these tests were used as performance measures. The remaining days were spent on other school required projects unrelated to the simulator evaluation.

Each day the four subjects were randomly paired and assigned to a schedule such that each pair went for a block of simulator training in both the morning and afternoon. The members of each pair alternately practiced on the simulator; while one trainee practiced, the other waited to use the simulator. Individual trials lasted until the trainee had correctly maintained the arc length for five minutes. The elapsed time of such a trial was approximately 7-1/2 minutes, the discrepancy resulting from arc length errors and the time required to reset the electrode and the target. As such, each E trainee was scheduled to receive 12 simulator trials per day for a total of 1-1/2 hours simulator practice or 9.75 hours for the 6-1/2 day period.

Because the simulator can be used in any of the basic welding positions, it was oriented to correspond with the welding position being practiced in the shop. The changes from the flat to the horizontal position and from the horizontal to the vertical position were made concurrently in simulator and shop training.

Trials were interrupted by the experimenter only if the trainee began showing signs of frustration. This generally resulted from the trainee making an inordinate amount of errors in relation to previous trials. A brief critique pointing out the reason(s) for the increase in errors would usually allay this frustration and permit him to finish the trial. Such intervention was rarely required after the first few trials during which the trainee was learning to discriminate between feedback tones and was getting used to the apparatus.

D. RESULTS AND DISCUSSION

To determine if E and C groups differed on level of performance, a Wald Wolfowitz "Run" Test was performed on visual and radiographic scores from plates one and two of the final vertical V-butt project. The four $\underline{z}$ scores were evaluated against a normal curve and indicated a lack of significant difference between groups. Further, not one trainee in either group reached the criterion level established for this experiment.

The failure to reach criterion and the lack of significant differences between groups may have resulted from: (1) a failure in the design to provide sufficient training time (i.e., attempting to complete a 10-day project in 6-1/2 days) and/or (2) the differences in actual training compared to those prescribed by the experimental design (see Table 1).

TABLE 1

Training Times Per Subject for E & C Groups

EVENT	E GROUP			C GROUP		
	Per Design	Actual		Per Design	Actual	
	Hours	Hours	% of Design	Hours	Hours	% of Design
Welding Practice	19.5	22.75	116	39	33	85
Simulator Practice	9.75	4.00	41			

Table 1 shows substantial discrepancies between designed and actual training times. These discrepancies resulted from an average 6-hour administrative loss (e.g., inspections, field days) for all subjects and an additional 4.25 hour loss for E subjects due to simulator downtime. The simulator downtime resulted from: (1) uneven and intermittent track motion, (2) power supply failures, (3) burned-up electrical wiring, (4) dragging rod, and (5) sticking arc length sensor.

During extensive periods of simulator downtime, E trainees were returned to the welding laboratory thus accounting for the 116% welding practice. However, the E group received only 41% of designed simulator practice and 19% less total training time than the C group. The latter percentage reflects the time E subjects waited to use the simulator. Thus, when considering the limitations under which this evaluation was conducted, combined with the inherent differences in training-time between E and C groups, it appears that the E group did at least as well and perhaps better than the control subjects.

Limitations to the latter conclusion are recognized. For example, the dependent variable used in this evaluation may have been too insensitive to indicate differences in favor of the C group. Or, the limitations placed on the design and conduct of this experiment including the small number of subjects examined may have prevented the C group from demonstrating superiority. Both arguments, however, could be used to support differences in favor of E group students, and the E group was operating under the disadvantage of even less training-time than the C group. Because of the importance placed on practice in skill acquisition, it is felt that this difference in training-time may account for the failure to find significant differences in favor of the E group.

E. Conclusions and Recommendations

Replying to the questions posed by this research, it appears that the simulator, with the physical modifications listed in Appendix C, may provide the desired welder practice. This conclusion is based on evidence that simulator trainees welded as well as conventionally trained subjects even though they had considerably less welding practice. However, prior to categorically stating that the simulator is, or is not, an effective training aid, procedures must be implemented to control for differences in training-time between E and C groups. If training-time is equated and if simulator trained students outperform their counterparts, then the value of its effectiveness will have been established.

While developing an effective training aid is unquestionably important, the potential advantages of the simulator go beyond reduced training-time and/or increased welder performance. The simulator provides definite advantages in terms of material savings (e.g., welding machines, power sources, electrodes, and metals) and increased training capabilities. Large scale use of the simulator could possibly: (1) enable welding schools to double the number of students by rotating blocks of trainees between simulator and weld-shop practice, (2) provide the means for on-going shipboard training under conditions where actual welding practice is not feasible, and (3) be used as a quantitative measuring device to select men with the greatest potential for success in welding schools.

Because of the benefits of incorporating the simulator into conventional arc welding training, SERVSCOLCOMSDIEGO desired continued expansion of its use. As such, that command and NPTRL have redesigned and constructed ten simulators which include the features listed in Appendix C. With the ten models, it will be possible to obtain more definitive answers on the effectiveness and potential of the arc welding simulator. It is therefore recommended that experimentation continue, employing two essential design features: (1) control for differences in training-time between E and C groups, and (2) more time to reach criterion.

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APPENDIX A

ANALYSIS OF WELDING SKILL DEVELOPMENT

APPENDIX A

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 reactions must be entirely dependent on the

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

exteroceptive cues from the welding process. His movements, however, provide 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 forgetting of 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 requires 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 requires 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.

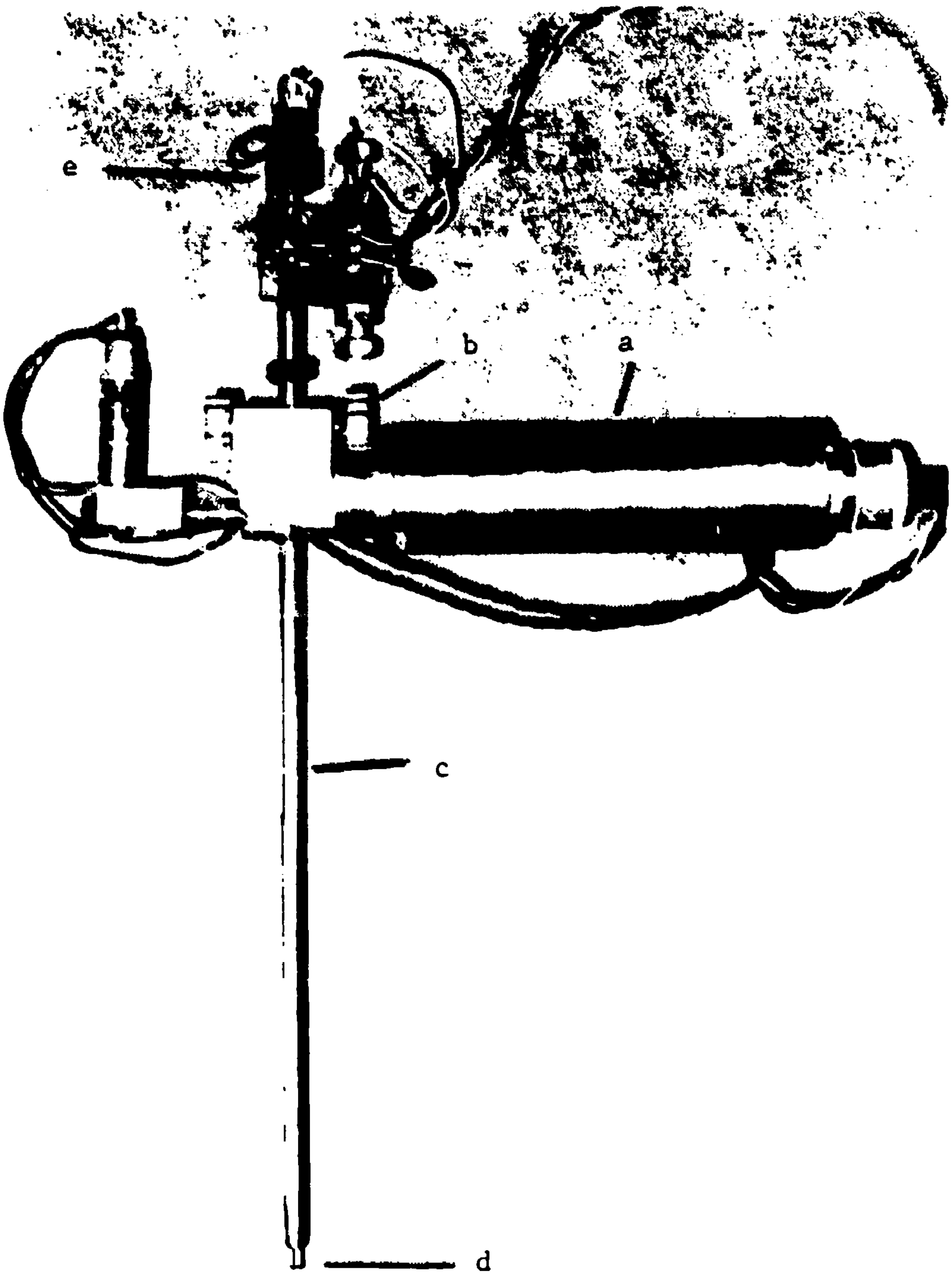
7. Wrist action in the side-to-side motion. In using the side-to-side motion, the beginning trainee has a tendency to use both arms or the whole welding arm to make the side-to-side motion. This does not work, because the proper side-to-side motion involves going rapidly across the center of the puddle 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

DESCRIPTION OF SIMULATOR

APPENDIX B

DESCRIPTION OF SIMULATOR[1]



A. Stinger and Rod

The stinger consists of a handle (a) containing a motor driving a pair of rollers (b). The rod (c) is driven by the rollers through a bushing in the stinger simulating the melting of the electrode in real welding. The rod consists of an outer metal tube and an inner clear plastic rod projecting from both ends of the tube. The plastic projecting at (d) represents the length of arc from the welding rod to the molten puddle in real welding. When the proper arc length is maintained, the plastic rod is illuminated by the bulb at (e) which is visible to the operator at (d). Also, at this time the motor in the handle is energized drawing the metal tube through the roller so that proper arc length must be maintained while the electrode is being "consumed". An electronically generated arc sound is sent through an amplifier.

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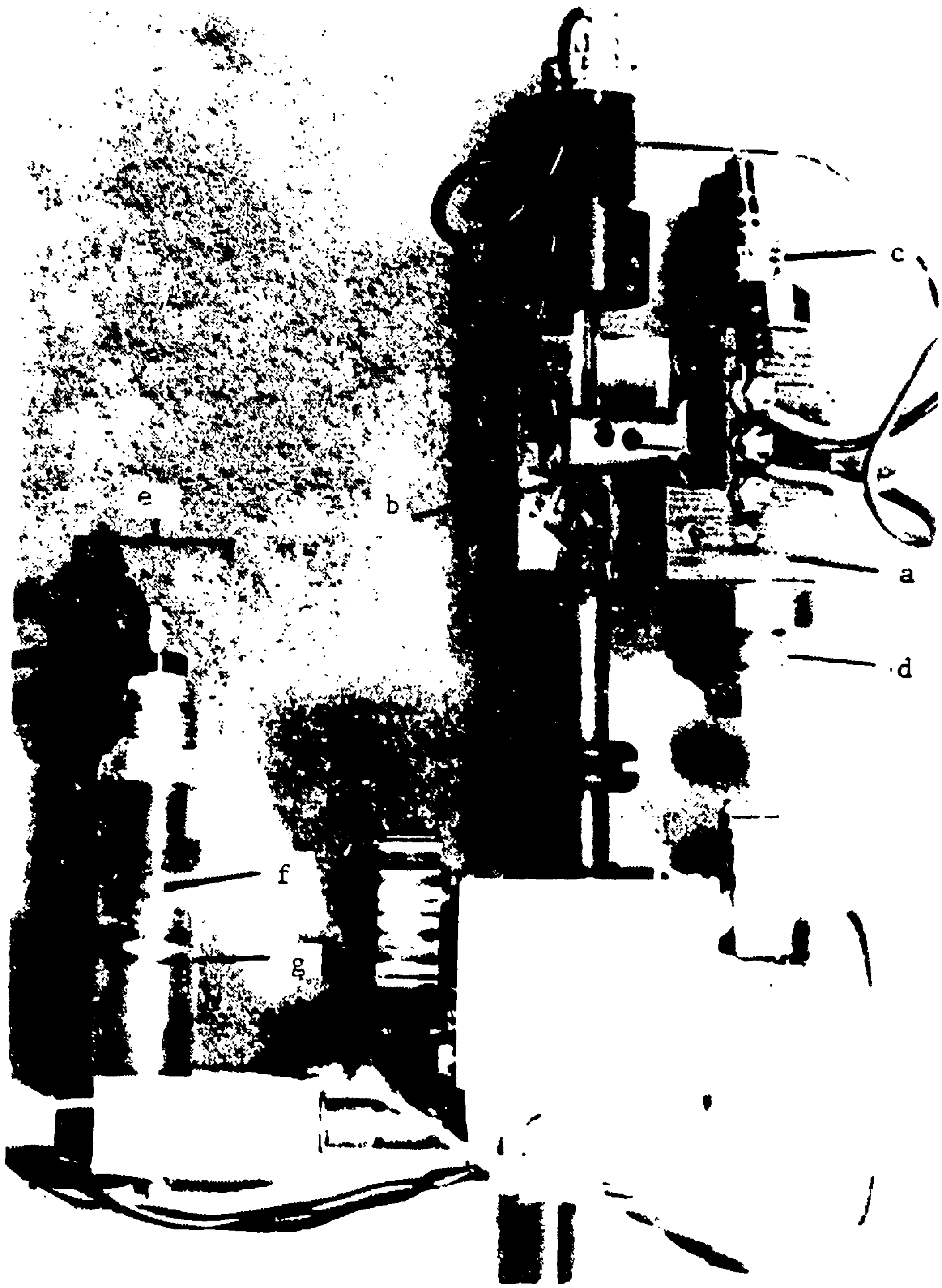
[1] This description is extracted from Disclosure of Invention submitted to Office of Naval Research on 13 April 1972, by coinventors Harvey B. Schow and Macy L. Abrams.



Proper arc length is sensed by a switch mounted on the top of the outer metal tube (a). If too much or too little of the plastic is allowed to project from the metal tube the sliding contact (b) makes contact with one of the adjustable limiting contacts (c & d). This energizes a relay which in turn turns off the rod illumination, the arc sound generator and the motor in the handle.

The welding electrode angle detector is mounted on the front of the stinger (e) and is adjustable for any welding position. When the proper electrode angle limit is exceeded in any direction, a small ball (f) rolls away from the center of a concave surface allowing light to fall on a photocell (g) in the center of the surface and causing an audio tone to be presented to the operator.

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B. Target-Welding Path

The box containing the moving target which simulates proper puddle manipulation (automatically conditions trainee to make proper movements) is shown in this illustration. The target consists of a photocell (a) mounted on a tracking mechanism (b) which moves the target in a forward motion along the weld path with an accompanying side-to-side oscillation simulating manipulation of the molten puddle. When the illuminated plastic rod is centered on the moving target, no operator feedback is present. But, when the rod moves off the center of the target the photocell is no longer illuminated and an audio feedback tone is presented to the operator.

C. Sensors & Feedback Circuits

(This information is considered privileged at this time.)

APPENDIX C

SIMULATOR MODIFICATIONS AND NEW FEATURES

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SIMULATOR MODIFICATIONS AND NEW FEATURES

Based on this evaluation, it was found that the simulator should incorporate the modifications and new features listed below. Ten models incorporating these changes are nearing completion.

DESIGN FEATURE	JUSTIFICATION
	STINGER
*1. Pushbutton reset of rod and track drive.	1. Permits more efficient practice; minimizes handling of equipment.
2. Encapsulated rod unit and angle detector.	2. Prevents inadvertent damage to sensors.
3. Encapsulated rod drive.	3. Eliminates damage to wiring; provides safer operation.
4. Simplified arc length limit adjustments.	4. Enhances ability to shape behavior.
*5. Pivoting stinger head.	5. Permits proper rod angles for all welding positions.
*6. Variable speed rod drive.	6. Enables matching consumption rate of all types of electrodes.
7. Increased intensity and stabilized arc tip illumination.	7. Ensures that state of sensitivity remains constant.

* These items reflect new design features.

APPENDIX C (Continued)

DESIGN FEATURE	JUSTIFICATION
TRACK UNIT	
1. Stabilized track drive.	1. Eliminates uneven target motion.
*2. Automatic drive reset.	2. Permits more efficient practice.
*3. Adjustable target motion.	3. Permits adjusting weave parameters.
*4. Variable continuous track speeds.	4. Permits adjusting speed to match the welding rate required for different types/thicknesses of materials.
5. Compact, smaller unit.	5. Permits fast, efficient change to different welding positions.
FEEDBACK/CONTROL UNIT	
*1. Speed controls for stinger and track motors.	1. Allows adjusting speeds for different welding conditions.
*2. Error recorders incorporated into unit.	2. Informs student of rate of progress.
*3. Plug in printed circuit boards and relays.	3. Makes for more reliable equipment and ease to maintain.
4. Compact, smaller unit.	4. Makes for more efficient use of equipment.
*5. Adjustable sensitivity of track and angle error detectors.	5. Enhances ability to shape behavior and ensures state of sensitivity remains constant.

* These items reflect new design features.

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13. ABSTRACT

Training effectiveness of a prototype arc welding simulator was evaluated by comparing 13 naive welding students trained under conventional methods with 14 subjects trained under the following experimental procedure: quarter-time simulator practice, quarter-time awaiting use of the simulator, and half-time actual welding practice. Preliminary data indicated that the simulator trainees, with substantially less welding practice and combined welding/simulator practice, performed as well as the conventionally trained subjects. However, prior to determining with certainty whether the simulator is an effective training aid, it was concluded that additional experimentation is required controlling for differences in training-time. A description and physical evaluation of the apparatus is provided as well as an outline of its potential advantages.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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