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STUDIES INTO INFORMATION PRESENTATION THROUGH NOVEL METHODS

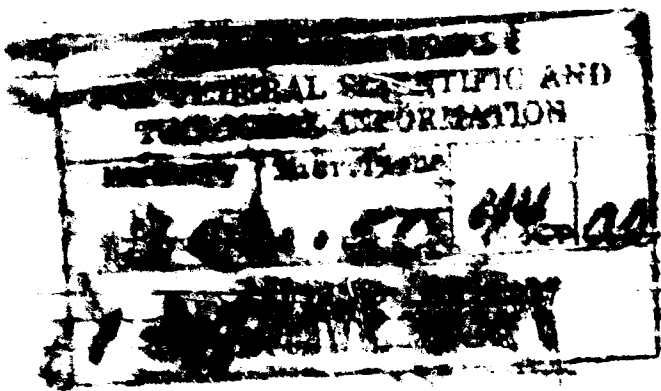
Two-Way Information Transfer through Electrocutaneous Transduction

Prepared For

U. S. Army Electronics Command
Fort Monmouth, New Jersey

Phase 11, Report

Contract No. DA 28-048 AMC-00186 (E)



Applied Psychological Services

Science Center

Wayne, Pa.

**Studies into Information Presentation through Novel Methods:
III. Two-Way Information Transfer through Electrocutaneous Transduction**

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ABSTRACT

This study, the eleventh in a program of research into information transfer through electrocutaneous methods, investigated two-way information transfer through electrocutaneous techniques. After brief training in reception and transmission of a simple vocabulary through electrocutaneous means and after orientation to the electrocutaneous transduction equipment, three two-man teams employed the vocabulary and the equipment to communicate with one another while jointly performing an experimental task. Two levels of time stress and three levels of attention sharing were imposed. Communication performance was scored, as well as performance on a collateral visual monitoring task. The results indicated that: (1) reasonably precise two-way electrocutaneous information transfer had taken place, (2) electrocutaneous communication performance was not degraded by the conditions of stress and attention-sharing, but (3) collateral task performance was degraded by stress and possibly by attention-sharing. It was concluded that the feasibility of the cutaneous sensory channel for supporting two-way information transfer in a limited vocabulary setting had been at least partially demonstrated. Some possible applications are discussed.

PURPOSE AND ACKNOWLEDGMENTS

A series of previous studies completed by Applied Psychological Services, under contract with the U. S. Army Electronics Command, has indicated that, under certain conditions, information transfer through electrical impulses applied to the skin of the operator in a military system may be practical and possess some advantage. However, these previous studies were concerned with unidirectional information transfer, tracking (perceptual-motor coordination), and monitoring situations. The purpose of the present study was to expand on these previous studies by investigating the potential of electrocutaneous information transfer in a two-man, interactive, bidirectional network. A further purpose was to investigate, within a restricted vocabulary and laboratory setting, the resistance of the electrocutaneous information transfer system to performance degradation as the result of time stress and attention sharing.

A number of others have continued to provide us with advice, support, and guidance. We are indebted to Paul Griffith and John Hennessy of the U. S. Army Electronics Command for their encouragement, thoughtful suggestions, and constructive criticisms. Newell Deacon helped us to overcome a number of the problems associated with the development of the research apparatus. Gail Rush and Estelle Siegel served as program secretaries and also prepared this report for printing. Our indebtedness to all of these persons is acknowledged.

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CHAPTER I

INTRODUCTION

This report describes the eleventh study in a series of investigations performed by Applied Psychological Services, for the U. S. Army Electronics Command, into the information transfer potential of the human integument. The intention of these investigations has been to examine, in a programmatic manner, the feasibility of applying, as a method of presenting information, low intensity electrical signals directly to the skin. Initial studies in the program examined the acceptability of this presentation medium to the human system; subsequent studies examined various aspects of the quality of the information transfer attending electrocutaneous stimulation. In all of these studies the information transfer had been unidirectional, i. e. , the subjects received programmed information and were required to take some action based upon this information. The present study was conceived as an attempt at extending the body of knowledge on electrocutaneous information transfer by investigating its applicability for two-way communication

Program Results in Review

Early studies in the program were directed toward determining the acceptability of electrocutaneous stimulation to the human system, both physiologically and affectively. No difference in such physiological reflectors

of reaction as heart rate, galvanic skin response, respiration rate or respiration amplitude, could be detected between electrocutaneous stimulation and presentation of comparable auditory stimuli (Macpherson and Siegel, 1964a). Then Lanterman, Macpherson, and Siegel (1964) investigated the affective qualities of electrocutaneous stimulation by means of a hedonic checklist and determined that the quality of the electrocutaneous signal employed was also acceptable from the affective point of view. In view of these indications of physiological acceptability and no psychological or affective aversive properties, attention was then turned to exploration of the use of this sensory channel for the transmission of intelligent information.

A rudimentary form of information transfer is associated with detection of the presence or absence of a signal, and detectability may be measured in terms of the time required to respond to the signal. Barcik, Lanterman, and Siegel (1964) conducted a comparative investigation of the detectability of electrocutaneous and visual signals. They measured simple and disjunctive reaction time in the performance of both cognitive and perceptual-motor tasks. Their data indicated no difference between the visual and the cutaneous channels in time to respond. These results were interpreted as being favorable to the use of electrocutaneous transduction, at least for rudimentary information transfer processes. Two other studies in this program, conducted by Macpherson and Siegel (1964b) and Lanterman and Siegel (1964), also explored the use of electrocutaneous transduction in rudimentary transfer processes; these studies investigated the applicability

of electrocutaneous signaling to a vigilance context, in which missed signals, as well as response latency, were the dependent variables. Threshold intensity (Macpherson and Siegel) and suprathreshold intensity (Lanterman and Siegel) signals were applied at low signal frequency rates through visual, auditory, cutaneous, and combined sensory channels. For single sensory channel monitoring, these studies indicated electrocutaneous monitoring to be reliably superior to visual monitoring, and probably superior to auditory monitoring, both with regard to latency and number of missed signals. The best monitoring/vigilance performance in these studies occurred, as might be expected, under conditions involving the redundant presentation of signals to two or more sensory channels. However, the redundant presentation of visual and auditory signal. resulted in performance that was reliably inferior to performance under any of the combinations involving electrocutaneous stimulation. That is, both the Macpherson and Siegel (1964b) and the Lanterman and Siegel (1964) studies indicated that effective monitoring performance was less a function of redundancy per se and more a function of the particular sensory channels involved in the redundancy, with highest quality performance occurring when one of the sensory channels was the cutaneous.

At this stage in the program, some potential for electrocutaneous transduction as a medium for information transfer appeared to have been demonstrated. However, signal detection and time to respond are relatively low in a behavioral hierarchy associated with information transfer.

Questions still remained concerning the amenability of the cutaneous sensory channel for supporting some higher order transfer processes and behaviors. Accordingly, a series of investigations was inaugurated into the use of electrocutaneous stimulation to convey higher order meaning. A compensatory tracking task was developed in which error signals were displayed cutaneously by means of a pair of electrodes fixed to the right and left sides of the lower torso. Performance of this tracking task was compared with performance of the same tracking task carried out with a visual display of errors. The tracking performance with electrocutaneous feedback was found to be of comparable quality to tracking performance with visual feedback (Siegel, Lanterman, and Macpherson, 1966). Then these investigators (Siegel, et al., 1966) examined utilization of electrocutaneous transduction for the receipt of information transmitted in Morse code. They found that qualified Morse operators could receive electrocutaneously at a signal rate of approximately one-third their auditory rate. The electrocutaneous channel was clearly inferior to the auditory for this task; however, substantial meaningful content information transfer had taken place cutaneously. Finally, in a step from the primarily sensory realm toward the more complex cognitive area of behavior, the suitability of electrocutaneous transduction for supporting probabilistic decision-making was investigated (Siegel, et al., 1966). In that study, Morse encoded information was transmitted to subjects who were required to use the information in developing and executing a game strategy. The quality

of the subjects' strategies was evaluated against the ideal strategy for the game, and comparisons were made between strategies that had their bases in auditory receipt of the information and those that had their bases in electrocutaneous receipt of the information. The results indicated no difference in the quality of the strategy developed, regardless of input sensory channel, and that all subjects developed strategies which well approximated the ideal strategy.

What had thus been examined in the program were several aspects of the acceptability to the human system of electrocutaneous stimulation and a reasonable range of information transfer processes predicated upon electrocutaneous transduction. Signal detection and reaction time had been studied in a number of contexts, tracking behavior was investigated as was code reception rate, and some evaluation of suitability for decision-making was obtained. All of these studies appeared to indicate potential utility of the cutaneous channel for the transfer of intelligent information. No study (except possibly those two investigating warning/intrusion/attention-commanding properties in vigilance contexts) indicated it to be the very best of all media of information transfer; but, realistically, panaceas were neither expected nor intended. All that was intended was a cautious exploration of the facets of information transfer that this sensory channel might feasibly accommodate. On the basis of the research conducted, there was reason to consider that many of the expectations for the potential of this sensory channel had been confirmed, at least for situations involving unidirectional information transfer. The two-way transfer of information had not been examined in the program.

Thus, the current study sought to extend the scope of the prior investigations into the area of two-way electrocutaneous information transfer. This study sought to investigate whether, in a limited vocabulary situation, individuals could communicate with one another and interact spontaneously when their only channel of communication was electrocutaneous. The three specific purposes of the study were to:

1. investigate the potential of the electrocutaneous channel for supporting back and forth spontaneous information transfer with sufficient precision so that intelligent actions could be based upon the information
2. investigate changes, if any, in the quality of the electrocutaneous information transfer process that might attend placing communicators under varying degrees of stress
3. investigate the effects, upon both the primary electrocutaneous communication task and a collateral visual task, of requiring operators to share their attentions across the two sensory channels.

CHAPTER II

METHOD

The methodology consisted of developing an experimental task which required two-man subject teams to "converse" electrocutaneously, conducting preexperimental training in a code which would be the "language" of the electrocutaneous communication, and then observing team communication performance over the repeated administration of two conditions of time stress and three conditions of attention sharing. In addition, observations were obtained of team collateral task performance over two conditions of collateral task requirements and two conditions of time stress. Data (error scores) relative to the two performance measures were analyzed through a series of nonparametric two-way analyses of variance. The remaining sections of this chapter describe each of the methodological steps in detail.

Experimental Task

The experimental task consisted of a modification of the game of "battleships." In this game, participants customarily place marks in some cells of a row-by-column matrix, each mark representing the deployment of a battleship (or an armored tank, or a squad of troops--the particular combat arm represented has no bearing on the conduct of the game). Each participant's deployment is kept secret from the other. Participants alternate in "taking shots" at each other's combat forces, by

specifying a row and column cell designation. A "hit" is recorded each time the row and column designation corresponds to that of an occupied cell; feedback concerning "hit" or "miss" is given immediately by the opponent. The winner of the game is the first one to destroy the other's forces or the one who has scored the most hits by the end of a prespecified time limit.

In order to use this game as a basis for the experimental communication task, certain modifications were implemented. First, matrices and the deployment of forces within them were prepared by the experimenters (rather than the game participants), so as to preclude the occurrence of any highly unique force deployments. Each matrix was a 25 cell square matrix within which five targets were deployed. Deployment was completely random except for the stipulation that, for every target-bearing cell, at least one of its contiguous neighboring cells would also contain a target. The reason for the stipulation was to introduce a small element of strategy into what was otherwise a game of pure chance; subjects were informed of this factor when the task was described to them. The second modification of the basic game was imposed solely for administrative purposes. This was to limit the duration of each game and to specify the limit in terms of a number of "shots" rather than an amount of time. Thus, all subject teams, whether they played rapidly or slowly, would take no more than the maximum permissible, ten shots per participant. Finally, all aspects of intra-team competition were removed from the psychological context of the game.

The game was presented to the subject teams as a task requiring cooperative performance. The subjects were told that team scores and not individual scores were the important data. The word "game" was not employed in describing the task to subjects.

Carrying out the experimental task required participants to communicate with one another. Specifically, each team member had to: (1) transmit to his partner the row-by-column alphanumeric cell designation of his "shot," (2) receive and understand the feedback from his partner on whether the shot had been a "hit" or a "miss," (3) acknowledge receipt of all messages, and (4) [when necessary] request repetition of any message he may not have understood. Subjects recorded their transmissions and receptions on log sheets that were provided. All of the communication was performed electrocutaneously, employing the signal code described below and the apparatus described in a later section of this chapter.

Communication Code

A 14-character communication code, based on different sequences of left-side/right-side stimulation, was developed as the vehicle for the electrocutaneous communication. Five different sequences of left-side/right-side stimulation identified the rows of the matrix, five more identified the columns, and four more sequences were necessary to construct a vocabulary of acknowledgment, "say again," and transitional terms. The full statement of the code employed appears as Table 1.

Table 1

Communication Code Developed for Experimental Task

| <u>Character</u> | <u>Sequence</u> | |
|------------------|-----------------|-----------------------------------|
| A | LRRR | WY means hit |
| B | LLRR | XZ " miss |
| C | LLLR | YZ " message received |
| D | LLLL | WX " repeat last message |
| E | LRLR | XY " review in sequence |
| | | YX " repeat last coordinates |
| 1 | RLLL | YY " disregard/I am sending again |
| 2 | RRLl | |
| 3 | RRRL | |
| 4 | RRRR | |
| 5 | RLRL | |
| W | LRLl | |
| X | LLRL | |
| Y | LRRL | |
| Z | RLLR | |

L = left
R = right

Apparatus

The apparatus constructed for the two-way electrocutaneous communication afforded the capability of transmitting and receiving signals electrocutaneously to the individual teams of subjects and monitoring electrocutaneously their own transmissions. Accomplishment of this involved construction of signal generation equipment, signal gating equipment, and signal reception equipment. A block diagram of the apparatus is presented as Figure 1.

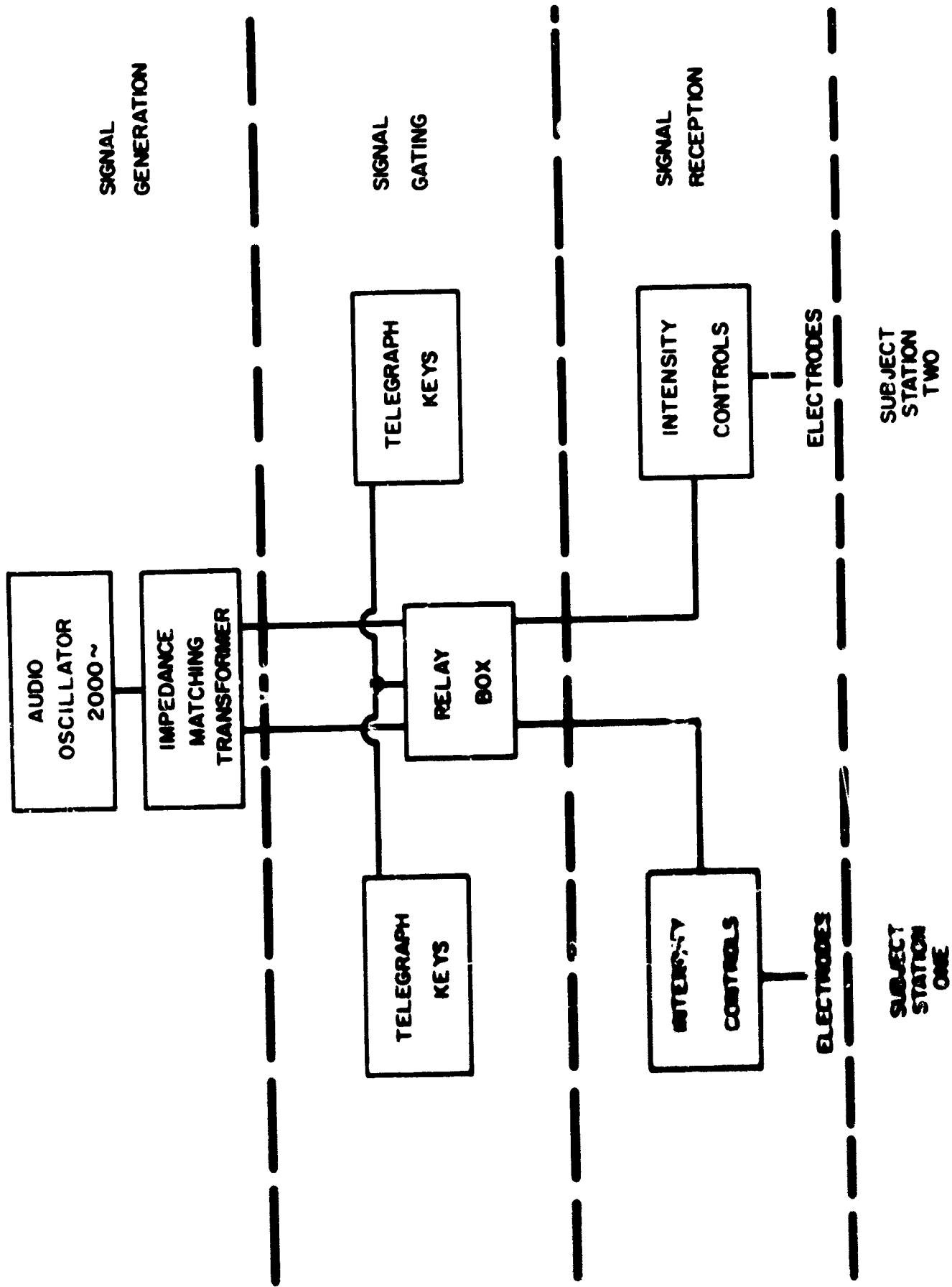


FIGURE 1. Block Diagram of Experimental Apparatus.

The input signal for this two-way communication system was a 2,000 cycle tone supplied by a Hewlett Packard model 200 A audio oscillator. The tone constituted the input to the primary windings of a UTC LS-12 impedance matching transformer. In the interest of providing independent signals to the two subjects, the signal was then tapped from two different 60,000 ohm secondary windings of the transformer and led to the signal gating equipment.

The signal gating equipment, installed between the signal generator/transformer and the subjects' reception equipment, constituted of a relay box and two pairs of standard Signal Corps telegraph keys. The relays were employed to present signals to the reception equipment of both subjects simultaneously. One subject required it as his primary signal; the other required it as his feedback signal. The apparatus was so constructed that a signal would appear either at the left side or the right side of the subjects' reception equipment, but a given signal could not occur simultaneously at both sides. In order to assure sharp signal onset and offset, mercury wetted relays were employed. Actuation of the gating relays was accomplished by depression of the telegraph keys. These keys were mounted side-by-side in front of each subject. The distance between the centers of the operating buttons of each pair of keys at a subject station was 1.5 inches; the keys were adjusted so as to minimize any auditory cues generated by their depression.

Signal reception for each subject was provided by means of a pair of 0.4 inch diameter, 60% lead - 40% tin, electrodes, flexibly mounted 0.75 inch apart on opposite sides of a small, smooth slat. These slats were mounted in a vertical orientation on the left side of the subjects' work stations, such that each subject was able to grasp the electrodes between his left thumb and forefinger. In addition to the lead-tin electrodes, a gold-plated indifferent electrode was fastened to each subject's left forearm. One subject reported some discomfort from this indifferent electrode. Accordingly, for that subject, a three-inch band of aluminum foil encircling the forearm was substituted for the gold-plated indifferent electrode. In view of the possibility that changes in skin resistance might occur and might alter the subjective signal intensity, an 18,000 ohm resistor was placed in series with each of the active electrodes. Finally, each subject was provided with individual intensity controls so that any difference in subjective signal strength between his two electrodes could be controlled. This was accomplished by means of two 100 K potentiometers at each subject station, each potentiometer affording control of the intensity of a right side or a left side signal.

Collateral Task

Since the operator attention sharing was an independent variable in this study, a collateral task was developed to be attention shared with the primary, communication task. The collateral task required the subjects to monitor a visual display and to detect and log signal deflections as they appeared. In one level of the attention sharing, signals occurred every 30 (±5) seconds; in another, they occurred every 90 (±5) seconds. Signal deflection was to one of the five, 0.5 inch separated positions above the horizontal centerline of the cathode ray tube of an EICO oscilloscope. The signal itself was a one inch horizontal line which was displayed at the CRT centerline when not deflected and, when deflected, remained at its new position for 4.5 seconds. The oscilloscope was draped so that only its CRT was visible. A placard, which labeled the signal positions, was placed over the tube face such that the signal appeared through a "window." This display was placed centrally between, and ten feet in front of, the two subject work stations.

The apparatus constructed for the collateral task consisted of a Gerbrand Timer programed to advance a stepping switch which drove the signal from the CRT centerline to one of the signal positions and then back to the centerline. The particular sequence of programed signal positions was established by a random procedure, as was deflection onset time within the boundaries of plus and minus five seconds.

Subjects and Preexperimental Training

The subjects for this study were six male college undergraduates who participated on a paid, voluntary basis. Following a brief orientation to the study, they were provided with a statement of the communication code (Table 1) and instructed to return two days later with the code committed to memory. There then followed two hours of training in receipt of the code with signals presented visually by means of a pair of indicator lights. All subjects attained a criterion of 72 consecutive perfect characters by the end of this visual training session. On the following day, subjects were given practice in receiving the code electrocutaneously. By the end of a two-hour session, all again attained the 72 character proficiency criterion. The next day, two-man teams were established on the basis of similarity in schedules of availability, and teams were given two hours of supervised practice in sending and receiving the code electrocutaneously. The final two-hour training session took place the following day. During this session, the established teams performed the full experimental task for no fewer than three trials, including one trial with the collateral task.

Independent Variables

The independent variables in this study were: (1) two levels of time stress, and (2) three levels of operator attention-sharing. Time stress was imposed by instructing subjects to complete the experimental task in less time than it had taken them previously (either the mean of all

of their previous times, or their immediately prior time, for subsequent trials within a day), and by placing a large Galab universal timer directly in front of the subjects at a distance of 12 feet. The levels of time stress were: (1) no stress, and (2) stress imposed as described above. Attention-sharing was effected by means of the collateral task, and the levels of this variable were: (1) no collateral task requirement, (2) performance of the collateral task in detecting visual signals deflecting with moderate frequency (once each 90 seconds), and (3) performance of the collateral task in detecting visual signals deflecting with higher frequency (once each 30 seconds).

Experimental Trials

The experimental trials took place in a quiet research room in which no one, other than the two subjects, was present. The subjects were seated on either side of a partition which obscured their view of each other. Their conformance to instructions prohibiting movement from the work station and prohibiting conversation was monitored by the experimenter through a one-way vision screen and a microphone connected to a speaker outside of the room. The setting for the experimental trials is presented pictorially in Figure 2.

The six combinations of the independent variables were administered within a repeated measurements design. With the exception that all teams were administered the no stress-by-no collateral task requirement condition first, the sequence of administration was random. Two experimental tasks

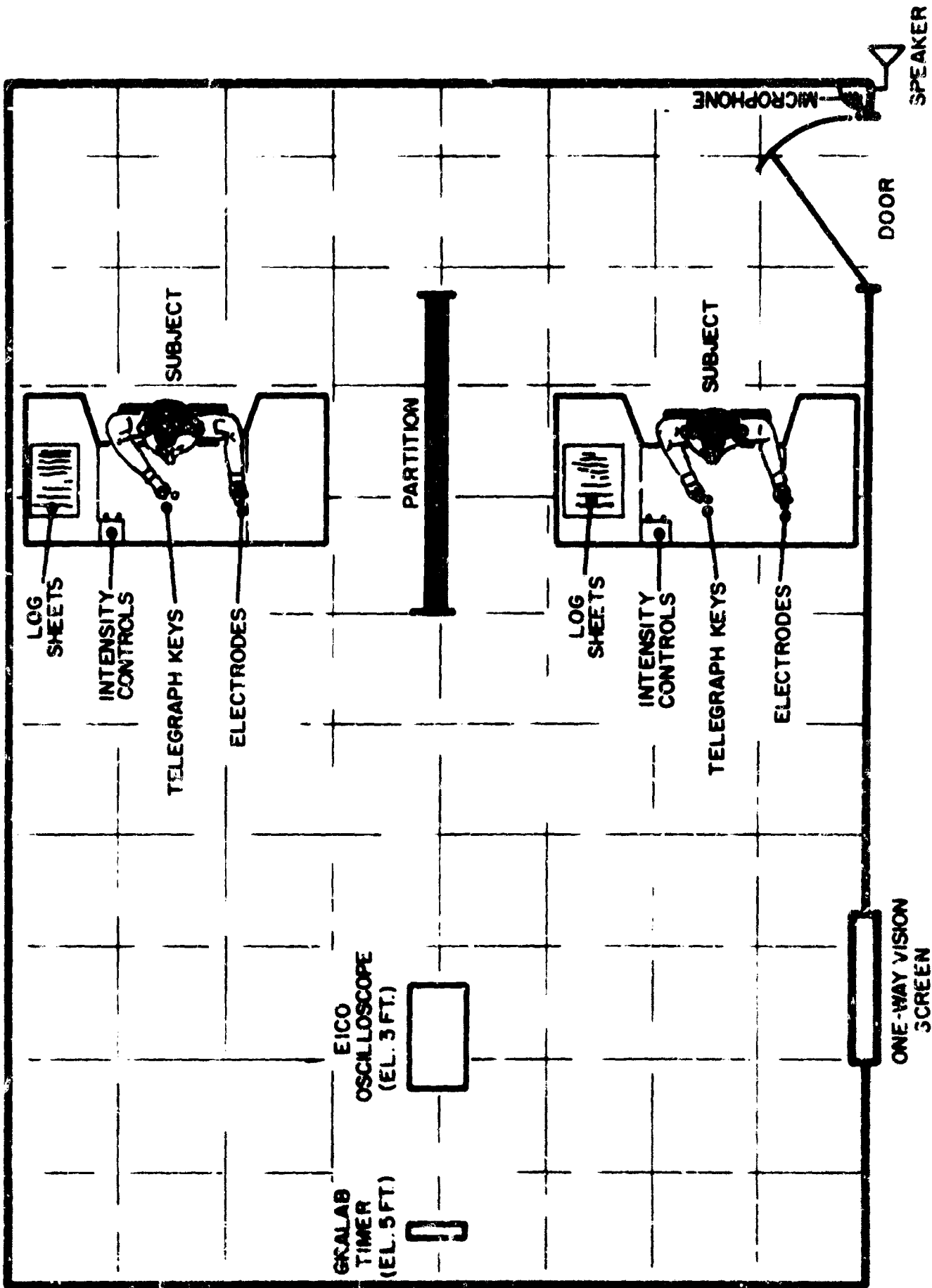


FIGURE 2. Plan View Of Experimental Setting.

were performed under each combination of levels. Two level combinations per team were administered each day. All data, including the repeated measurement of three teams over two levels of time stress and three levels of attention sharing, were collected within a ten-day period following training.

Data Analysis

The dependent variable data of this study were communication errors and visual monitoring errors. A communication error was defined as any reception which did not correspond exactly to the antecedent transmission; this included both incorrect receptions and requests for repetition. A visual monitoring error was defined as any failure to detect the incidence or proper magnitude of programmed signal deflections. The ratio of the total number of communication errors to the total number of communication attempts was calculated over the two experimental tasks performed by each team under each combination of experimental conditions. In completely parallel fashion, the ratio of the total number of visual monitoring errors to the number of programmed signal deflections was also calculated for each team under those combinations of conditions requiring visual monitoring. These yielded two three-dimensional matrices of stress-by-attention sharing-by-teams, each containing one value per cell. The first matrix, communication performance, was $2 \times 3 \times 3$ the second, of visual monitoring performance, was $2 \times 2 \times 3$ inasmuch as no visual monitoring data were obtained under the condition in which no attention sharing was required.

In view of the Poisson curve of probability encountered with error scores, the nonparametric approach to data analysis was selected as being the most direct. Accordingly, the data were analyzed through nonparametric methods. Each of the two three-dimensional matrices was divided into three two-dimensional matrices. The two-dimensional matrices were then successively subjected to statistical test by the analysis of variance by ranks. In addition to the analysis of variance tests, results of postexperimental interviews with subjects, and over-all task performance were subjected to qualitative examination.

CHAPTER III

RESULTS

The experimental task was performed without untoward incident by all subject teams under all experimental conditions. In all cases, the teams completed their 10 shot games within less than 30 minutes. The shortest game time was less than 11 minutes. In addition, six games were terminated after fewer than the full 10 shots because five hits had been made. All subjects reported the experience to be pleasant and found neither the novel communication medium, nor any of the stressing agents, to impose any hardship upon them.

The distribution of communication errors per communication attempts, calculated over both team members for both games played under each experimental condition, is shown in Table 2. Table 2 indicates that the two-way communication performance was reasonably error-free. The modal error rate was between seven and eight per cent; this value was also the median of the distribution. What is not indicated by Table 2, which is based on communication attempts, is that of the 36 individual games played, four were played with perfect communications (i. e. , no errors) and six more games were played with error rates of only two and three per cent.

Table 2

Distribution of Communication Errors per Communication Attempts
(proportions based upon 114-155 attempts)

| <u>Proportion of Errors</u> | <u>Frequency</u> |
|-----------------------------|------------------|
| 0.00 | 0 |
| 0.01 | 0 |
| 0.02 | 2 |
| 0.03 | 1 |
| 0.04 | 2 |
| 0.05 | 0 |
| 0.06 | 1 |
| 0.07 | 3 |
| 0.08 | 3 |
| 0.09 | 2 |
| 0.10 | 1 |
| 0.11 | 0 |
| 0.12 | 1 |
| 0.13 | 1 |
| 0.14 | 0 |
| 0.15 | 0 |
| 0.16 | 0 |
| 0.17 | 0 |
| 0.18 | 0 |
| 0.19 | 1 |
| 0.20 | 0 |

Table 3 presents the results of the nonparametric analyses of variance of the communication scores. In view of the exploratory nature of this research and the small number of degrees of freedom, Type II error (failure to reject a false null hypothesis) was considered to be the more serious, and the criterion level of statistical significance was set relatively low ($p \leq .20$) so as to minimize the probability of a Type II error. This procedure is consistent with statistical hypothesis testing procedures as described by various writers. For example Lindquist (1953, p. 67-68) points

out that "...it is not always desirable to set a very high level for the test of significance. . . other things being equal, the higher the level of significance of the test, the greater is the danger of retaining a false hypothesis"; and Winer states that "The frequent use of the .05 and .01 levels of significance is a matter of convention having little scientific or logical basis. [Under certain conditions] the .30 and .20 levels of significance may be more appropriate than the .05 and .01 levels" (Winer, 1962, p. 13). With regard to the established significance criterion of $p \leq .20$, the data of Table 3 indicate that the two-way electrocutaneous information transfer process appears to be resistant to: (1) varying degrees of operator stress and (2) varying degrees of operator attention-sharing requirements.

Table 3

Results of Nonparametric Analyses of Variance
of Team Communication Performance*

| <u>Analysis</u> | χ^2 | <u>df</u> | <u>p</u> |
|-----------------------------|----------|-----------|----------|
| Stress by Team | 0.33 | 1 | >.20 |
| Attention Sharing by Team | 2.00 | 2 | >.20 |
| Attention Sharing by Stress | 1.00 | 2 | >.20 |

* Number of communications errors per communication attempts.

The data of Table 3 presented results of analyses of communication performance. Recognizing that, in an attention-sharing setting, performance on the collateral task also constitutes an indicator of the utility of the primary information transfer channel, comparable analyses were conducted of visual monitoring performance.

Table 4 presents the distribution of visual monitoring errors per the number of programed signal deflections again calculated over both team members for both tasks performed under each experimental condition that required visual monitoring. This table shows that, in central tendency, visual monitoring performance was essentially comparable to communication performance (modal error rate between 6 and 10%). It should be noted that although a 19% error rate was the worst communication score (Table 2), one-third of the visual monitoring data exceed this error rate.

Table 4

Distribution of Visual Monitoring Errors per Number
of Programed Signal Deflections
(proportions based upon 30-66 and 126-204 deflections)

| <u>Proportion of Errors</u> | <u>Frequency</u> |
|-----------------------------|------------------|
| 0.00 - 0.05 | 0 |
| 0.06 - 0.10 | 4 |
| 0.11 - 0.15 | 3 |
| 0.16 - 0.20 | 1 |
| 0.21 - 0.25 | 2 |
| 0.26 - 0.30 | 1 |
| 0.31 - 0.35 | 0 |
| 0.36 - 0.40 | 0 |
| 0.41 - 0.45 | 0 |
| 0.46 - 0.50 | 1 |

Table 5 presents results of the analyses of variance conducted upon the visual monitoring scores. If one accepts the same statistical significance criterion established for evaluation of communication performance ($p \leq .20$), it may be seen in Table 5 that differences in collateral task performance as a function of operator stress appear reliably greater than chance expectancy. Table 5 also shows that differences in collateral task performance attributable to attention-sharing are not reliably greater than chance when tested against interteam differences, but when results are pooled across teams and the variances are tested across the four conditions, the hypothesis of no difference must be rejected.

Table 5

Results of Nonparametric Analyses of Variance
of Team Collateral Task Performance*

| <u>Analysis</u> | χ^2 | <u>df</u> | <u>p</u> |
|-----------------------------|----------|-----------|-----------|
| Stress by Team | 3.00 | 1 | >.05 <.10 |
| Attention Sharing by Team | 0.33 | 1 | >.20 |
| Attention Sharing by Stress | 2.00 | 1 | >.10 <.20 |

* Number of collateral task errors per number of programmed signals.

CHAPTER IV

DISCUSSION

The purpose of this investigation was to extend the scope of prior investigations of electrocutaneous information transduction into the area of two-way electrocutaneous communication. Specifically, the present study sought to investigate, first, the potential, if any, of the cutaneous sensory channel as a medium for supporting back and forth "conversation," and, second, degradation in the quality of the information transfer when operators were stressed and/or required to share their attentions between cutaneous and visual sensory channels.

With respect to the question of whether two-way electrocutaneous information transfer took place, the results quite clearly indicate that it did. In this limited vocabulary situation, subjects carried out two-way electrocutaneous "conversations" with sufficient precision that they were able to complete all of the games played and were able to base intelligent planning actions upon the information transmitted between them. Within the restrictions imposed by the experimental task where, with the exception of acknowledgments and requests for repetition, messages were primarily of a two-digit alphanumeric type, subjects were able to interact spontaneously with one another utilizing electrocutaneous transduction as their sole intercommunication medium. The evidence for inferring that the two-way transfer process took place is restricted not only to the facts that: (1) all games were completed, (2) the games were completed in reasonable time, and (3) some were even completed in fewer than ten shots,

but also the error rate data indicate that the information transfer process was of fairly good quality. Particular note is taken of the games played with perfect communications and of those played with only two or three errors per every 100 transmissions. Even the modal error rate of seven to eight errors per every 100 transmissions can be considered acceptable in view of the very abbreviated training that was provided to the experimental subjects.

The data regarding the influence of stress and attention-sharing upon operator performance are more difficult to evaluate. It is obvious that neither of these variables effected any change in the quality of communications performance (Table 3). This finding could be interpreted as indicative of the resistance of electrocutaneous transduction to various kinds of operator loading. That is, if electrocutaneous transduction were a marginal communication medium, one might expect communications to "fall apart" with the introduction of loads upon the communicators. As Table 3 shows, communications did not degrade. However, for the conditions which required operators to monitor a visual display in addition to communicating, although their communication performance did not suffer, their visual monitoring performance did. The quality of the visual monitoring performance "fell off" as a function of the stress imposed, and it may have fallen off as a function of increased collateral task requirements. Thus, depending upon which criterion measure one invokes (communication performance or collateral task performance), he has evidence to support either of two incompatible inferences

In the authors' opinion, there is a reconciliation of these apparently incompatible results. The study was presented to the subjects as a communication study. The largest portion of the training time was devoted to communications: the code, the experimental task, practice receiving and practice transmitting. To the subjects, the primary task was communication and playing the game of "battleships." The secondary task was monitoring the visual display. It therefore seems reasonable that, given a choice point in an attention-sharing context, a subject would sacrifice what he believes to be of secondary importance in favor of what he believes to be primary. In the present study, with the psychological set described above, this means that subjects attended primarily to the quality of the communications. If time/opportunity permitted, they accommodated the collateral task. It would thus follow that any performance decrement that was going to occur would manifest itself in the secondary task--and this is exactly what a comparison of Tables 3 and 5 shows.

What does this information mean to the practical decision-maker? First, the apparent paradox in the data examining the influence of certain other factors upon electrocutaneous transduction in an attention-sharing setting should not detract from the principal finding of this study; namely, that the cutaneous sensory channel was capable of supporting limited two-way communication. Second, for the decision-maker who is interested in the quality of the communication process and only the communication process, no evidence of communication degradation was obtained over any of

the conditions of this study. For the decision-maker who is interested in how well the cutaneous sensory channel lends itself to attention-sharing with the visual channel, the only data available concern the case where the cutaneous channel was apparently considered to be the more important. Here, cutaneous performance remained relatively unchanged, while visual performance was degraded by stressing the operators. In the absence of a direct comparison with other channels (e. g., auditory), it is not known whether these effects would have been greater, lesser, or the same for other channels. Third, it is completely possible that, if the communication task had been considered of secondary importance to the visual task, stress and increasing collateral task demands would have degraded the electrocutaneous communications. However, (1) degradation under stress and the requirements of a competing task is not unique to the cutaneous sensory channel, and (2) if an estimate of the extent of secondary task degradation can be gleaned from the data of Table 4, we see that degradation to zero did not occur (i. e., in the worst case, at least half of the programmed signal deflections were properly detected) and that the modal secondary task error rate was something less than ten per cent.

Potential Applications of Electrocutaneous Transduction

The research in this program has indicated potential applicability of electrocutaneous transduction to a number of contexts. Because of the obtrusive properties of the electrocutaneous signal, it may be singularly

qualified for alerting purposes. Whether it succeeds in commanding attention because of a novelty effect or because of inherent channel characteristics will require longer range research to determine; however, this method of information transfer would seem to possess some very desirable attributes for alerting personnel. Unlike the visual channel which is highly directionally oriented (i. e., an operator with his back to an instrument panel will not see an alerting light on that panel), the cutaneous channel is omnidirectional and inescapable once the operator is tied into the loop. This attribute can be of value in alerting an operator to significant visual or auditory signals about to be transmitted to him.

Unlike both the visual and the auditory channels, the cutaneous channel is relatively underloaded in today's military systems. Personnel receive voluminous inputs from visual display panels frequently while they are also receiving inputs via radio/interphone. Adding additional visual indicators to already saturated display panels, or adding additional override circuits to the auditory assembly, may be adding as much noise as signal to the information flow. Utilization of the cutaneous channel, either for primary input or redundancy, may afford an opportunity to unburden the visual and auditory channels.

The cutaneous channel is private. The attention of one operator in a multioperator room can be summoned without disturbing the others from their tasks. Information of relevance to one position in a multiposition station can be transmitted to that position only with no interference to other positions.

For tactical military situations, electrocutaneous transduction would permit transmitting instructions to personnel with markedly reduced risk of disclosing positions. The signal is silent. It affords the enemy no visual indication either of movement (as a runner might), of color and brightness contrast (as smoke, flares, or flashing lights might). The current study has expanded the potential realm of applicability of electrocutaneous transduction for tactical situations. While the prior research suggested tactical potential for transmitting instructions to deployed personnel, the present research indicates some possibility that such personnel may be able to report back through electrocutaneous means. Thus, the possibility is open that scouting and/or infiltration patrols might utilize electrocutaneous transduction to maintain continuous contact with their command post, to provide field commanders with critical intelligence information immediately, to send planning information about other tactical targets, and to receive immediately and in secrecy the results of decisions whether to divert to those targets.

It is thus possible, based upon the various studies of this program, that wireless, transistorized, electrocutaneous transduction equipment may eventually provide the increased flexibility without increased vulnerability that can be of assistance in tactical settings, and "hard mount" electrocutaneous transduction equipment may possibly be of assistance in the display monitoring, man-machine interfaces, of other military settings.

CHAPTER V

SUMMARY AND CONCLUSIONS

This study investigated two-way information transfer through electrocutaneous transduction. The purpose was to determine, on an introductory and exploratory level, the feasibility, in a limited vocabulary situation, of spontaneous back and forth information flow between two operators when their only input sensory channel was cutaneous. Ancillary purposes were: (1) to assess changes in the quality of the transfer process that might attend when communicators are placed under varying degrees of time stress, and (2) to examine the effects, upon both communication performance and performance of a collateral visual task, of requiring operators to share their attentions across the two sensory channels.

An experimental task was developed which required two-man subject teams to communicate electrocutaneously, and a code was developed to be the language of the communications. Three two-man subject teams were trained in the code and then observed in repeated performance of the task over two levels of time stress and three levels of attention sharing. The dependent variable measures were communication errors and visual monitoring errors. The data were analyzed by nonparametric analyses of variance.

The results indicated that all subject teams performed the two-way communication task without difficulty and with low error rates. Concerning differential effects relative to the communications performance criterion, no evidence was obtained of any degradation in quality as a function either of stress or of increasing collateral task requirements. Relative to the visual monitoring performance criterion, statistically reliable degradation was observed as a function of stress and as a function of collateral task requirements.

On the basis of this investigation of two-way information transfer by electrocutaneous transduction, the following conclusions seem warranted:

1. two-way information transfer by electrocutaneous transduction can take place, at least in limited vocabulary contents
2. two-way electrocutaneous communication flow seems resistant to at least moderate amounts of operator stress and attention-sharing requirements
3. further study of channel potential and amenability to attention-sharing with other sensory channels may be indicated.

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| 13. ABSTRACT This study, the eleventh in a program of research into information transfer through electrocutaneous methods, investigated two way information transfer through electrocutaneous techniques. After brief training in a code and orientation to the electrocutaneous transduction equipment, three two-man teams employed the code and the equipment to communicate with one another while jointly performing an experimental task. Two levels of time stress and three levels of attention sharing were imposed. Communication performance was scored as well as performance on a collateral visual monitoring task. The results indicated that: (1) reasonably precise two-way electrocutaneous information transfer had taken place, (2) communication performance was not degraded by the conditions of stress and attention-sharing, but (3) collateral task performance was degraded by stress and possibly by attention-sharing. It was concluded that the feasibility of the cutaneous sensory channel for supporting two-way information transfer in a limited vocabulary setting had been at least partially demonstrated. Some possible applications are discussed. | | | |

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